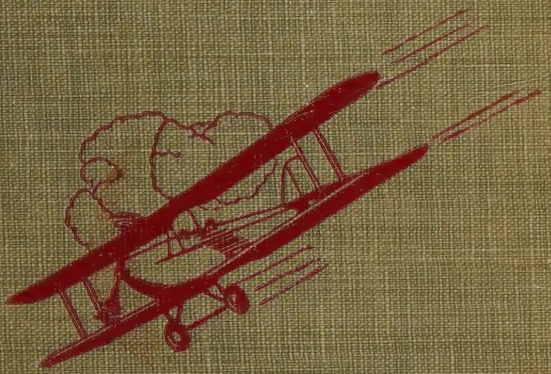
The ABC of FLIGHT



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THE A B C OF FLIGHT

THE ABC OF FLIGHT

BY

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ASSISTANT TO VICE PRESIDENT
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WITH A FOREWORD

BY

HON. EDWARD P. WARNER

Asst. Sec. of the Navy for Aeronautics

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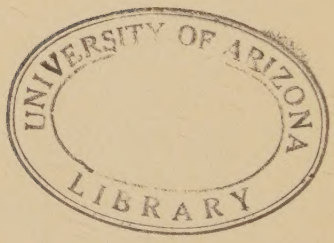

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FOREWORD

THE layman often has an unfortunate tendency to take science and invention and their fruits for granted. Of those who have not had to pursue studies of physical science for professional reasons, many are wont to accept its marvels as gifts of the gods, and to seek no further into their origin. We turn the switch and the electric light flashes up, and it is the exception for us to reflect either upon the processes of research that underlay the development of the incandescent bulb or upon the enormously complex industrial and engineering structure that insures reliability and economy of the service. We pull our cameras open and press the button without troubling ourselves over the physical process of bringing an image to a focus upon the film or about the chemical manipulations whereby its record is permanently fixed there. Enthusiasm for the acquisition in an amateur way of scientific and mechanical knowledge has become more widespread in recent years, but it is an enthusiasm often unguided, lacking text and manual for its instruction.

Mr. LePage, proceeding from an extended experience with aeronautical research engineering and the practical application of economics to aircraft operation, has undertaken to rectify any such deficiency in the aeronautical field. Without requiring from his readers any previous knowledge of

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physics beyond what arises out of everyday observation, he has developed as complete an explanation of aerial navigation as is likely to be needed by any one not professionally specializing in that field. For the reader of his book there need be no mysteries in air travel. He will recognize the processes of climbing, of banking for a turn, and of landing, when he experiences them, as well-understood phenomena no more complex or uncanny than those attending the swinging of an automobile around the street corner.

It is a real service to contribute to the destruction of the illusion that flying is a special branch of magic, characterized by awesome and unpredictable behavior of the aircraft. Nothing happens in the air in contravention of natural laws, and indeed there is nothing in aeronautical science that cannot in a general way be simply discussed in terms of simple analogy with such everyday occurrences as the impact of a jet of water from a hose against a wall, the flight of a tennis ball when struck, or the way in which the draft forms behind the windshield of an open automobile. Mr. LePage has labored to make clear that essential simplicity, when discussed in general terms of cause and effect, of actions and reactions of which the detailed quantitative treatment, to be sure, becomes inordinately complex. The volume which results from his labors deserves wide attention.

EDWARD P. WARNER,
Asst. Secretary of the Navy for Aeronautics.

WASHINGTON, D. C.,
March, 1928.

PREFACE

POISED in a medium so thin that we can breathe it, the modern airplane in flight is as firm and steady as a rock. Cross winds will blow and gusts will burst, but the airplane, steadied by the very gusts and cross winds which originate the disturbance, will fly smoothly on its way, rocking and jerking no more than does an automobile riding over a smooth concrete highway. Such is the degree to which the air has been harnessed by modern aerodynamics.

The past year has seen rapid strides in the development of aviation, characterized not only by recent outstanding accomplishments but by the ever-expanding system of commercial air transport services in this country and in Europe. As a result of this remarkable progress the airplane has veritably become a part of our everyday lives. Yet the mysticism which has clung to this great achievement of modern engineering ever since its pioneer days is still withholding confidence in travel by air.

Shortly after Colonel Charles A. Lindbergh made his memorable New York-Paris flight in May, 1927, the author recommended to the Editorial Board of the *Christian Science Monitor* that the publication of a series of articles setting forth in the simplest of terms the fundamentals of the Science of Flight and the construction and piloting of the airplane would do much to create confidence in travel by air,

assuming the truth of the axiom, "knowledge breeds confidence."

Considerable space in this daily newspaper was given over to the series of articles by the author which forms the basis of the present work. The favorable reception which attended the publication of this series constitutes the reason for the reproduction of the work in book form.

In the following pages the reader is taken through the entire theory of the flight of an airplane and considerable effort has been put into explaining each step in the simplest possible manner, defining carefully every new term as it occurs. The construction of airplanes is dealt with in a similar way as is also the operation of the aircraft engine. Finally, the reader is taught to fly, and while there is no pretence at being able to replace the practical instruction obtainable at a reliable flying school, the chapter on flying instruction, together with those dealing with theory and manufacture, is offered the reader with every confidence in its being of very material value to him as a preliminary to his following a course in actual flying.

Coming, as it does, in the twenty-fifth year of power driven flight, this little book is a distinct sign of the times for it presages the entry of aircraft into common usage in our daily lives, a condition which could not be realized until the principles, "whys" and "wherefores" of flight are common knowledge.

W. LAURENCE LEPAGE

PHILADELPHIA, PA.
March, 1928.

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THE ABC OF FLIGHT

CHAPTER I

Fundamental Principles of Flight

It is not unusual, when one hears of an entirely new idea which has been developed, that one exclaims, "How simple! Why didn't I think of that before?" In fact it is invariably the case that a new thought or idea, upon its explanation, appears strikingly simple. It is not, for instance, unlikely that the invention of the first wheel by the ancients was heralded as a perfect marvel, while today, and in fact for years immemorial, it has seemed almost inconceivable that so simple a thing as a cart wheel should ever have assumed the rôle of a new invention. And so it is with aviation; for this new art, which may well appear to us to represent the very acme of achievement is, in reality, but the result of an orderly and systematic application of long existing theorems of physics which we ourselves have for centuries been applying in our everyday lives.

The desire to throw off yet another bond of limitation and soar up into the air has been in-

herent in many for centuries, and it is of considerable interest to note that from the earliest experiments no new and as yet unlearned theories were looked for, but merely a new application of existing and already established facts. Thus, the very earliest natural scientists who achieved any success in their endeavors to fly above the earth, based their work entirely upon their observations of the rising of hot air and smoke from a fire.

The Montgolfier brothers of France, who built the first balloon, applied their observation of the fact that hot air was lighter than cold air and, therefore, would rise above cold air, to successful advantage. Their achievement was outstanding, but it was rendered possible simply by their ability to harness rising heated air and make it lift their balloon aloft. And so it is with the theory of the airplane, or with "heavier-than-air" flying, as it has been termed to distinguish the flight of an airplane from that of a balloon or airship, which may be referred to as "lighter-than-air" flight.

The basic and one essential factor in all forms of flight, whether of the lighter-than-air or the heavier-than-air variety, is sustentation. In the case of the former, this is secured by means of buoyancy.

The buoyancy of a body in air (just as it would be in water) is the difference between the weight of the body and the weight of the air (or water) displaced by that body. An airship filled entirely with air would have no buoyancy, for there would

be no difference in weight between the air in the hull of the airship and the air displaced by the airship. If, however, the air is pumped out and the airship is filled with hydrogen, which is very much lighter than air, the airship will immediately be buoyed up, for the simple reason that the weight of the ship is now very much less than the weight of the volume of air which it displaces, and sustentation is thus achieved.

The theory of sustentation in heavier-than-air flying, i.e., that of the airplane, is hardly more complicated. As in the case of the airship, it depends entirely upon the application of long existing fundamentals. Air has weight, namely about 13 cubic feet to the pound. It, therefore, has resistance and obeys Newton's laws, the most simple of which establishes the fact that where there is action there is, of necessity, reaction. It is this reaction which enables flight in a heavier-than-air structure like an airplane. Moreover, an airplane is so designed that this reaction is as firm and as solid to an airplane wing as a concrete roadway is to the wheel of an automobile.

If a thin flat plate is held parallel (edgewise) to a stream of air there will, generally speaking, be no reaction or force applied to that plate. If, however, the plate is rotated through 90 degrees and is held in the stream of air (Fig. 1, A) there will be a reaction upon the plate which is expressed by the arrow (R). This reaction is exactly equal in quantity to the force exerted by the plate upon the

air, tending to retard its forward path, but it acts in a direction opposite to that of the retarding force. This force (R) has been termed the Resistance or Drag of the flat plate when placed at right angles to the air stream.

Assume, now, that a mean position for the flat plate (Fig. 1, B) is chosen between that parallel and that at right angles to the air stream. The law of action and reaction still applies. The air stream will be deflected downward by the flat plate in much

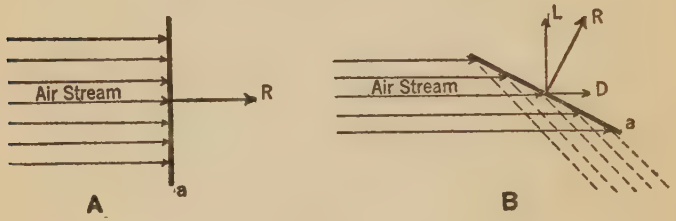


Fig. 1.

the same manner as light is reflected by a mirror. This deflection is the "action." The "reaction" is still perpendicular to the medium producing the action, i.e., the flat plate, and is shown again by the arrow (R). However, under the new disposition of the flat plate this reaction force provides something of what we are looking for, namely, sustentation, although an examination of the direction in which this force (R) acts reveals it as being not purely a sustaining force.

There is, for example, still an element of Resistance or Drag in the reaction as is evident from

the fact that the direction of the force slopes in the direction of motion of the air stream. The arrows (L) and (D), derived by a simple mechanical resolution of forces, represent, respectively, the pure sustaining force and the pure resistance force which are compounded in the reaction (R), and the lengths of these arrows represent the proportion in which these two forces go to make up the total reaction (R).

Herein lies the basic idea of heavier-than-air, or airplane, flight, the only difference between its theory and that of the airship being that in the latter case the Lift or sustentation is static, while in the former, the lift is purely dynamic.

It should, of course, be realized by the student of aeronautics that motion is at all times purely relative, and that it matters not to the theory whether the flat plate is held stationary and the air stream caused to flow past it, as in the forerunning discussion, or whether the reverse is the case and the flat plate is caused to move through still air. The action and reaction are in both cases identical with the resultant Lift and Resistance forces as indicated.

This fact is clearly shown in the flight of a boy's kite. If there is a strong wind blowing, the kite will stay high up in the air with little effort on the part of the boy who holds the kite line. If, however, there is little wind blowing, the boy finds he must run fast with the string in his hand in order to keep the kite up. In this way he creates motion between the kite and the surrounding air, this being the only

requirement for its flight, which in either case is the same.

It has been shown how the reaction of the air upon a moving inclined flat plate will produce a Lift force, at the same time setting up Drag, a resisting force tending to retard the forward motion of the plate. This latter is, of course, a detriment in actual flight since it does not contribute to sustentation and power is required to overcome it.

Thus, it will be seen that the problem is twofold. The inclined flat plate, acting as a wing and with suitably applied power, will enable us to fly. But while it is very obviously necessary that the Lift force be maintained as great as possible, the Drag, which resists forward motion and is, thus, detrimental to the very factor which supplies our Lift, must be kept at a minimum. A compromise is, therefore, necessary and it will be seen, as the study of flight continues, that the entire problem is eventually answered by means of compromises.

The Lift set up as a result of the forward motion of an inclined plate is due to two factors. In the first place, the air passing under the plate will be deflected downward. Thus, we have a vertical action upon the air in a downward direction which must, according to Newton, be accompanied by a similar and opposite reaction in a vertically upward direction.

Secondly, the air which passes over the upper surface of the flat plate is unable to change its direction with sufficient rapidity to follow down the in-

clined back of the plate. The tendency, therefore, is for a void or partial vacuum to be created at the point where the air stream breaks away from the back of the plate. Where there is a partial vacuum there must, of necessity, be suction which, in this case, acts vertically on the plate. It will readily be seen that this suction adds materially to the total vertical reaction or Lift of the plate.

As a result of extensive experimental work, it has been found that by far the greater part of the Lift is caused by the suction over the upper surface of the flat plate or wing. In fact, from three-fifths to three-quarters of the total Lift is due to this suction, the remaining two-fifths or one-quarter being due to the compression of the air under the wing.

In view of this interesting fact it is obvious that when an effort was made by the pioneer aeronautical engineers to increase the lifting ability of a wing, which might be formed of a simple flat board, attention was directed toward increasing the suction rather than the compression. It was found by experimental work that by giving the flat plate thickness and curving or cambering its section so that the maximum thickness was near the front edge and the section tapered off in thickness toward the after edge, the suction over the upper surface would be increased considerably and, consequently, the Lift greatly improved.

The result was a cambered section wing for airplanes such as that shown in Fig. 2, a, which also

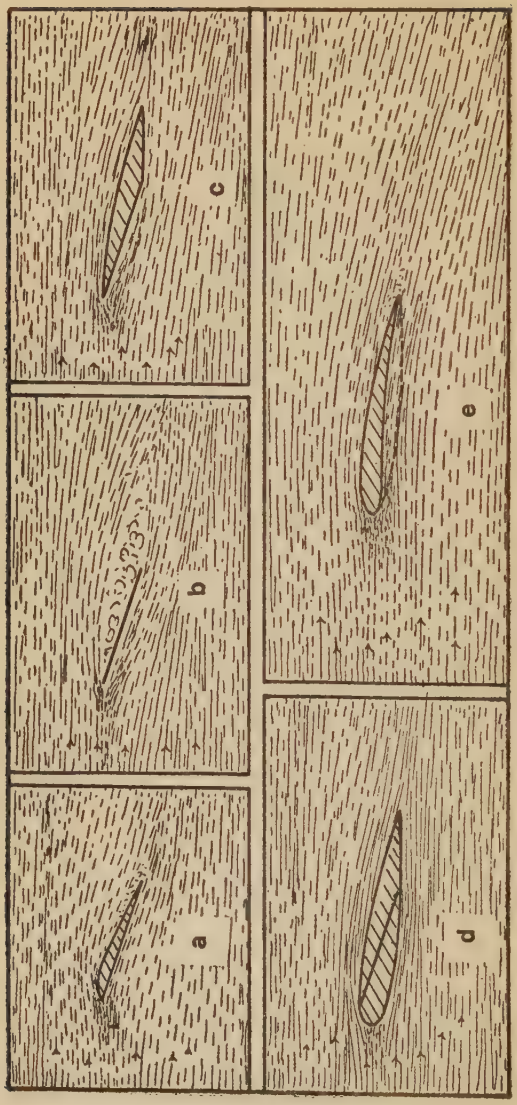


FIG. 2.—Illustrating the derivation of the streamline wing section.

shows how the air passing over and under the wing is deflected downward to cause Lift. However, as already indicated, wherever there is a change of direction enforced there will, of necessity, be a resistance to that change, and the Drag of the wing is very largely accounted for in this manner.

This Drag force must obviously be minimized as much as possible. One way of doing this would be to arrange the flat plate so that it is edgewise to the direction of motion. This, however, would not do, for the plate must be inclined in order that we may secure the necessary Lift. Accordingly, what is called "streamlining" is resorted to. The process of streamlining is that of causing an obstacle or other body moving through air to conform as far as possible to the natural form taken by the stream of air in passing that body.

In Fig. 2, b, the inclined flat plate from which we secure our Lift force, is shown with the streamlines of air passing it (or caused by its relative motion) and the turbulent region directly behind the plate will instantly be recognized as a serious source of resistance to forward motion. If this turbulent region can be eliminated by so shaping the back of the flat plate that its surface conforms to the natural streamlines of air passing it, the Resistance of the plate will have been very greatly reduced (see Fig. 2, c).

Another step toward reducing the head resistance of the plate may be taken in streamlining its forward surface in a similar manner (see Fig. 2, d).

Now, while we have thus considerably reduced the Drag of our flat wing by these modifications, it will also be observed that we have destroyed those features of our flat wing which cause it to exert a Lift. Accordingly, we may attempt to compromise between the perfect streamline section of Fig. 2, d, and the flat plate, and develop a section for our wing similar to that shown in Fig. 2, e. An examination of this new section will reveal its resemblance to that which we have already developed from our flat plate when we were considering only the problem of increasing its Lift.

Thus, we have been able, by a simple process of logical step-by-step modifications, to develop a wing shape which is superior to a flat plate in that it not only has a greater facility for producing a Lift when moving through the air, but presents a lower Resistance or Drag to the air and consequently, requires less power to drive it.

It is interesting to note that in the early days of aviation development, the pioneers, looking to the birds for information which might lead to the construction of a successful man-carrying airplane, discovered that in cross-section the bird's wing was curved or cambered, and while the camber of a modern airplane wing is by no means similar to that of a bird's wing, the precedent for the cambered wing is there. However, we have developed, as it were, the cambered wing of an airplane from basic fundamentals. We have established upon an aerodynamic basis the superiority of the curved-section

wing over the flat plate and we can now proceed to a consideration of the actual forces which make flight possible with the aid of wings of this type.

In Fig. 3 we have a cambered airplane wing shown under flying conditions. A close examination of the diagram will reveal the fact that we have provided the forward pull of the propeller in the form of what is called the Thrust, and this force

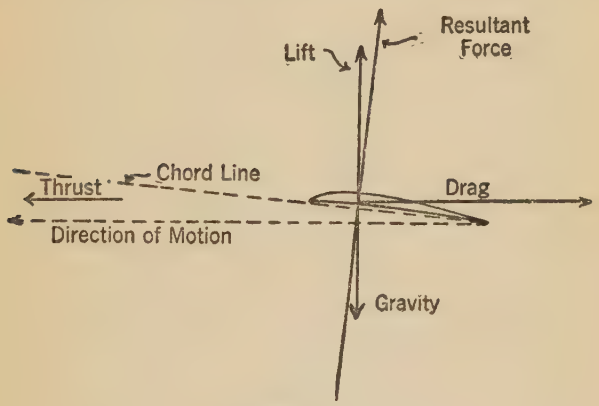


Fig. 3.

directly overcomes the Drag of the wing. For the purposes of this early discussion, it will be unnecessary to give any consideration to the presence of the other parts of the airplane, such as the body, the tail, etc.

Since the Thrust overcomes the Resistance, or the Drag, of the wing, there will be a forward direction of motion, as indicated. In order that there should be a Lift, it is necessary that the wing should be

tilted upward at the front edge, so that there shall be a pressure on its under surface and a suction over its upper surface. There will, therefore, be an angle formed between the Direction of Motion and what is called the Chord Line of the wing, which is an imaginary line joining its leading and trailing edges. (The actual Chord length is the width of the wing along this line. It should be pointed out that this line may actually pass through the section of the wing, in thick wings, or may merely touch the leading and trailing edges, as in the case of Fig. 3.)

This angle between the Direction of Motion and the Chord Line, known as the Angle of Incidence of the wing, is, in fact, the one factor other than speed which determines the amount of Lift, provided by the wing, as we shall shortly see. In an efficient wing the Resultant Force, which is the compound of the Lift force and the Drag force, is nearly vertical, owing to the comparative smallness of the Drag, its horizontal component. Actually, this force could never become vertical since such a circumstance would indicate the complete elimination of Drag—an impossibility.

As the Angle of Incidence of the wing is increased, so the Lift will become greater because of the more violent reaction which it will have upon the passing air. The Drag, too, will go up rapidly although, in an efficient wing, i.e., one having a good section, not nearly so rapidly as does the Lift. Consequently, the Resultant Force will continue to remain nearly vertical.

In Fig. 4, line (a) represents the increase in Lift with increase in the Angle of Incidence, and permits the relationship between the two to be visualized. The diagram was obtained by measuring off verti-

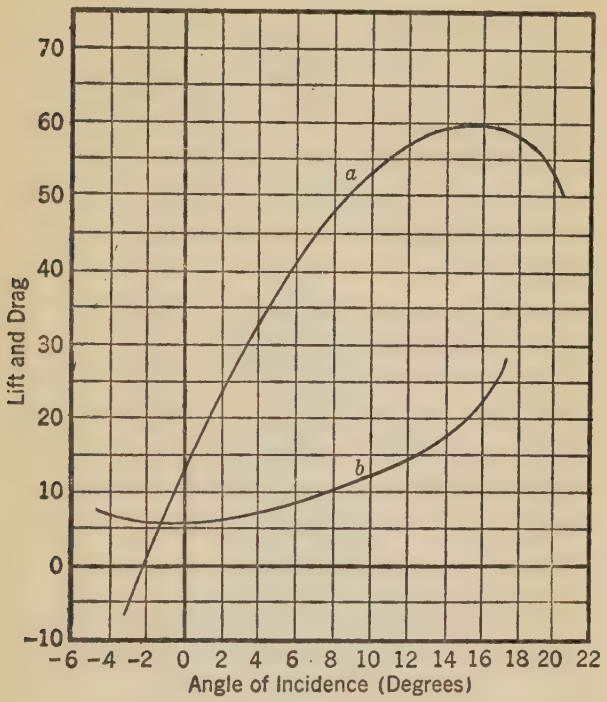


Fig. 4.

cally the amount of Lift for a certain wing at different Angles of Incidence along the horizontal base of the diagram and joining the points so obtained. A close examination of the curve will reveal that

as the Angle of Incidence is increased, the Lift goes up very rapidly at first but slowly falls off until there comes a time when a further increase in the Angle of Incidence will no longer be accompanied by an increase in the amount of Lift. In the average wing this condition is approached in the neighborhood of 16 degrees of Incidence. It is due to a breaking away of the air flow over the upper surface of the wing, resulting in a violently turbulent condition in place of the steady suction which, as has already been pointed out, contributes so largely to the Lift of the wing.

Instead of creating Lift, this turbulence at high Angles of Incidence contributes only to the Resistance or Drag which, consequently, shoots up rapidly, bringing the Resultant Force sloping far backward, and thus completely ruining the efficiency of the wing. When the Angle of Incidence of a wing is increased to this point, the Burbling Point is said to have been reached, and the wing is said to be Stalled.

In Fig. 4 again, the curve (b), similar to that for the Lift, is drawn for the Drag of the wing, and represents the change in this factor with increase in the Angle of Incidence. The Drag, it will be seen, goes up gradually as the Incidence is increased, until the Stalling, or Burbling Point, is reached, when, owing to the breaking up of the smooth air flow over the upper surface of the wing, the Drag shoots up rapidly. Obviously such a condition is to be avoided in flight since the sudden and very rapid falling off

PLATE I.

The Junkers three-engine, 1200 horsepower airliner with cabin accommodation for 15 passengers.

in the Lift with the colossal increase in Drag will instantly bring an airplane down. But the student, while he should learn of this condition, need have no concern on this point since the airplane which he will later fly will be provided with complete control devices which will prevent such an occurrence under normal conditions.

Thus, we have established these definite and unchangeable factors of Lift and Drag as inherent in our wing surface. Given the correct sectional shape and maintained in the proper attitude, nothing short of flying into a vacuum can deprive such a wing of its Lift provided there is relative motion between it and the surrounding air. How true it is that the air is, to an airplane wing, as firm and as solid as the concrete highway is to the wheel of an automobile.

CHAPTER II

How Stability and Control Are Achieved

What a common thing is an airplane! So common, in fact, that we hardly take the trouble to look at it twice as it flies overhead and yet, how many of us have asked ourselves, "Why is an airplane shaped like an airplane?" One possible answer might be, "Because a bird is shaped like a bird," and yet everyone will admit that a modern airplane is sufficiently unlike a bird to make the reason for this unlikeness interesting. Moreover, many early types of airplanes were most unlike birds, resembling nothing in particular, but so lacking in grace and beauty that the merest novice might see their shortcomings.

The reason an airplane is what it is to look at, is not merely because the aeronautical engineer has had a fancy for making his product resemble the work of nature, but because the theory of flight, based upon well-established physical laws, demands that it should be so. The bird's wing is curved or cambered in section; so is that of an airplane, but in the preceding chapter we have built up sound aerodynamic reason for this peculiarity of the airplane wing. The fact that the conclusions arrived at as a result of our study are similar to those gov-

erning the products of nature only goes to confirm the logic of our reasoning.

Let us, therefore, continue our research into the peculiar qualities of this cambered wing which we have developed, and attempt to build up our airplane as we progress, in order that we may develop the perfect product and know that our development is sound because of the logic of our reasoning.

It has been established that when a surface, which we will call a wing, is moved through the air a Resultant Force is developed due to the reaction between the wing and the air passing over and under it. This force, acting upon a complete airplane wing, may be described as the compound of an infinite number of small forces acting at all points of the surface. Obviously, then, there must be a theoretical point about which this compound force may be considered to center. This theoretical point is known in aeronautics as the "Center of Pressure" of the wing, and its position varies with the Angle of Incidence.

In practice, the Center of Pressure of a certain wing is usually considered as the imaginary line drawn parallel to the span of the wing joining the "fore-and-aft" centers of pressure of an infinite number of sections of the wing which together go to make up the entire wing span. In the case of a flat surface moving through the air this Center of Pressure line is close to the front edge at small Angles of Incidence, and moves backward as the Angle of Incidence is increased, until at 90 degrees

of the flat plate to the wind, the Center of Pressure line runs across the center of the plate (see Fig. 5).

In a cambered surface, such as a modern airplane

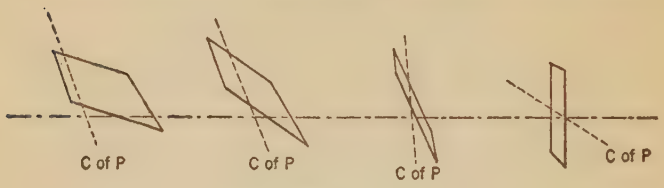


Fig. 5.

wing, the movement of the Center of Pressure line is entirely different, being, in fact, far more complex. As will shortly be seen, it is this fact which, in reality, accounts for the general shape of a modern airplane. At small Angles of Incidence, owing to the air pressure upon the dropping front edge of a cambered wing, the Center of Pressure line is situated some little distance back from the front edge (see Fig. 6). As the Angle of Incidence is in-

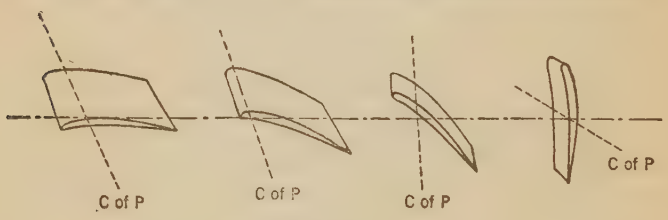


Fig. 6.

creased, instead of the Center of Pressure moving back, as in the case of a flat surface, it moves forward. With continued increase in the Angle of Incidence of the cambered wing the Center of Pres-

sure again changes its direction of movement and starts backward until, at 90 degrees, its position is, as in the case of the flat surface, along the center of the wing.

Because of this somewhat erratic Center of Pressure movement, the cambered wing is what may be described as unstable. If, at a small Angle of Incidence, a gust of wind or other outside disturbance tends to throw the nose of the wing up, the fact that the Center of Pressure moves forward will tend to throw the nose up still more and thus further increase the Angle of Incidence. Obviously, then, there is no tendency for the wing of itself to become restored to its original position, and an outside agency must be brought into play.

With this in view, then, let us add to our cambered wing, out of which we are going to build our airplane, a flat surface which we may call the tail plane, since it will be placed in the rear of the main wing (see Fig. 7). In order that our cambered wing will have a Lift, we must give it an Angle of Incidence which we shall set at eight degrees, purely for the purpose of discussion. We do not yet know what to do with the tail plane, so that we may as well leave it at zero Angle of Incidence.

Now, let us consider our skeleton airplane flying in the direction shown by the arrow A (Fig. 7). Because of the fact that we have not given our tail plane an Angle of Incidence there will be no Resultant Force on this plane, the main wing doing all the lifting. (The weight of the tail plane will, of

course, have to be balanced by a suitable weight ahead of the main wing). Suppose that a sudden gust of wind should come up and momentarily increase the Angle of Incidence of the main wing (see Fig. 7, upper diagram). Owing to the pull of the propeller in the new direction, our skeleton airplane will start to climb, and, as we have already seen, because of the unstable Center of Pressure movement of our cambered wing, the airplane will continue to climb steeper and steeper, until the wing reaches its

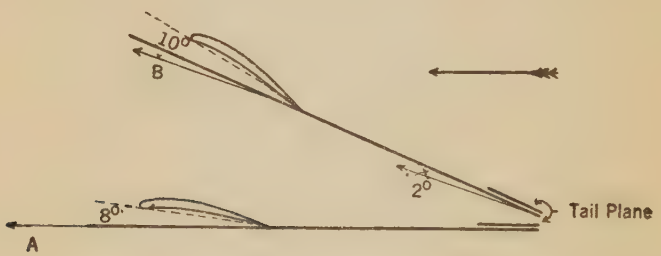


Fig. 7.

Burbling Point and stalls, with a sudden drop in its lifting capacity and the resultant fall of the machine.

This, however, is where the tail plane comes into play. At the moment of striking the gust of wind, the skeleton airplane will have considerable momentum in the horizontal direction in which it has been traveling. Consequently, until this momentum has died out, its new direction, as a result of the gust, will not be quite parallel to the pull of its propeller. Let us suppose it is 2 degrees off, as indicated by the arrow in Fig. 7. The effective Angle of Incidence

of the main wing will, therefore, be increased from 8 degrees to 10 degrees, an increase of only 25 percent. The tail plane was originally set at zero Incidence, but it will now have an effective Incidence of 2 degrees, a far greater change.

Obviously a Lift will immediately be exerted by the tail plane which previously presented no vertical reaction whatsoever. This lift force, having its effect at a point far behind the main wing, will have a very much more marked effect upon the attitude of the plane than the relatively small increase in vertical force on the main wing. Consequently, the tail will immediately rise and correct the upsetting effect of the gust, thus restoring the skeleton airplane to its original condition of horizontal flight. It will be readily seen that in the same manner a similar restoring effect will be influenced by the tail plane in the event of a gust forcing a reduction in the Incidence of the main wing.

Our modern airplanes, therefore, all have tail planes which stabilize them longitudinally and enable them to maintain a horizontal course. Thus, they resemble closely a bird in this particular, but not without our having a very good reason for making them so. A curved or cambered wing is a most unstable thing, and yet when it is forced through the air it has almost remarkable lifting qualities, so that airplane designers have had to be satisfied with its drawbacks from the standpoint of stability and devise some means of overcoming them. Nor is this the only stability problem to be overcome, as we

shall later see. In the meantime, however, we have the essentials of the airplane worked out, and, provided that we can supply the necessary power for driving the wing through the air, we should be able to achieve horizontal flight, at least in theory.

The motive power of an airplane is supplied by an engine, usually a gasoline engine not altogether unlike that of our automobiles. But more than a mere engine is necessary, since we have to provide a means of propulsion through the air. Except in the legendary days of aviation, when all kinds of contrivances ranging from sails to paddles were suggested as a means of propulsion for flying machines, the screw propeller has been the accepted means of traction for both airplanes and airships. Since most modern airplanes are pulled rather than pushed through the air, it would seem more appropriate to talk of a "tractor" in referring to the screw which provides the necessary tractive power, but the term "propeller" has become the accepted name.

In theory, an airplane propeller is identical with a marine propeller in that it screws its way forward through the medium in which it operates. In practice an airplane propeller usually has two long narrow blades which are set at an angle to their respective directions of motion when turning. With a view to making this clearer, it may be said that if the propeller were to be immersed in butter it would, for each revolution, screw its way forward a definite distance somewhat in the same manner as a wood

screw bores its way through a chunk of pine wood (see Fig. 8).

Of course, owing to the fact that air is so thin compared with butter, our "airscrew" will not make nearly so much headway per revolution as it would were it revolving in a medium as thick as butter. In air, the medium will tend to slip away from behind the blades as they turn and, consequently, there will

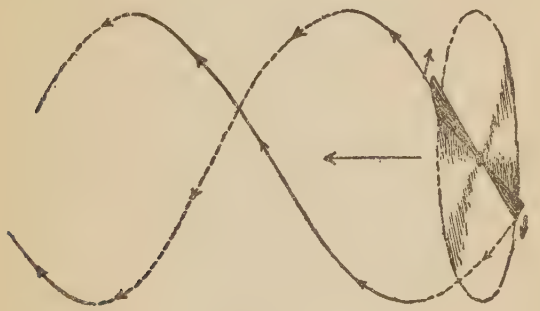


Fig. 8.

be a strong draft of air swept backward by the propeller. This is known as the "slipstream," and anyone who has been to an airdrome to watch the flying and has stood too near behind a plane as the engine was being tested, will clearly remember losing his hat and wiping the grit and dust out of his eyes—all caused by the slipstream!

With the motive power provided for, it is now only necessary for a suitable body to be arranged to hold the wing and tailplane in their cor-

rect relative positions, and to carry the pilot and the engine (propeller attached), and flight should be possible. However, the airplane must have wheels which will enable it to run along the ground while it gains sufficient speed for flight, i.e., until the Lift of the wing is equivalent to the weight of the machine; and some means must be provided for steering the plane and controlling its climbing and diving. It must be recalled that the tailplane of itself will merely maintain horizontal flight.

Furthermore, while the tailplane, as we have seen, will provide horizontal or longitudinal stability there are other directions in which stability is necessary during the flight of our airplane. Stability, it must be remembered, is an inherent ability to maintain an initial direction of motion and to resist all outside tendencies to change the state of equilibrium. We have yet to give consideration, therefore, not only to the means of control of our airplane but also to the complete problem of stability in flight.

Already it has been seen that unless it has been set at an Angle of Incidence, a flat plate will have no Resultant Force whatsoever other than a horizontal resistance. The tailplane, it will be remembered, is set at zero Angle of Incidence and only assumes a positive (or negative) Incidence when the horizontal equilibrium of the airplane is disturbed, and then only maintains this Incidence momentarily—until equilibrium is restored.

Under normal circumstances, then, there is no

vertical force on the flat tailplane except momentarily during a disturbance.

However, let us consider a horizontal flat plate with a flap hinged all along its rear edge. Provided that the flap stays in line with the plate and that the latter is at zero Angle of Incidence to the air flowing by it there will be no Resultant Force set up other than the Resistance (see Fig. 9, A).

If, however, the flap is moved up or down, what was formerly a flat plate now takes on something of

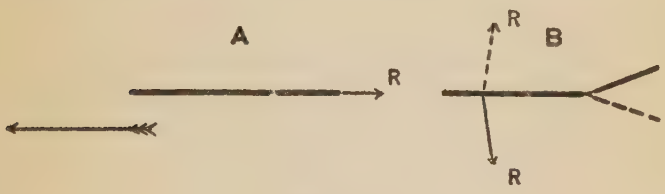


FIG. 9.

the aspect of a curved surface and, accordingly, there will be either a positive (up) or a negative (down) Resultant Force set up (see Fig. 9, B). Here, therefore, we have a means whereby the tailplane can be employed not only for securing longitudinal stability but also for providing a means of longitudinal or "up-and-down" control.

Raising the tail flap, which is known as the "Elevator," will produce a negative Resultant Force upon the tail of the airplane, which will start to drop, and this will result in an increase in the Angle of Incidence of the main wing. This, as has already

been seen, will be accompanied by a greater Lift. Accordingly, the airplane will climb and will continue climbing until the elevator is returned to its original position and horizontal equilibrium is restored. Of course, it stands to reason that more power will be required for climbing than for level flight and, consequently, the engine will have to run faster at the same time that the elevator is raised. For similar reasons, depressing the elevator will result in a reduction in the Angle of Incidence of the wing with a corresponding decrease in the Lift, the airplane starting to dive.

A similar movable flap, which we shall call the "Rudder," arranged vertically at the tail of the airplane will serve as a means of controlling the direction of flight.

That the airplane is not such a complicated mechanism in essentials as we had formerly been led to suppose is evident when we review our progress and see how, as a result of the application of only one or two fundamentals we have developed the airplane into something which is beginning to resemble the real thing (Fig. 10).

There is, however, more to learn. In spite of the fact that our airplane is beginning to look right, the reader would be much surprised were he to realize fully how utterly impossible it would be to fly the machine in its present stage of development. The airplane has a rudder, but it is by no means controllable; it has a wing and a tail, but it is so unstable that it would be impossible for it to leave

the ground without crashing. These problems and their solution must all receive our attention.

Stability is a problem which has perplexed aeronautical engineers and airplane designers as much as, if not more than, all other problems. The basic reason for this is simply the fact that the greater the freedom of motion, the greater will be the stability problem. Consider, for example, an auto-

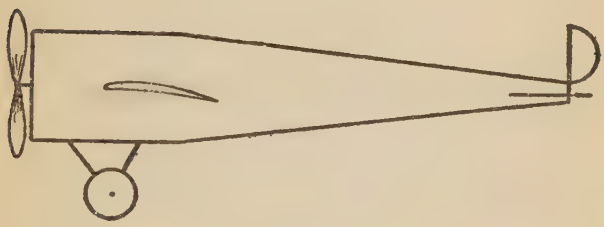


FIG. 10.

mobile. Its control, and to a certain extent its stability directionally, are the only factors vested in the skill of the driver. As far as fore-and-aft pitching is concerned, this is (with the exception of the springing) governed by the contour of the roadway, while the roll, if such a term can be applied to a car, is likewise governed, presumably, by the camber of the road.

In an airplane, the conditions are entirely different. In Fig. 11, our airplane developed to the present stage is shown in perspective. It will be seen

that three axes have been drawn through the probable Center of Gravity of the machine, namely, the Longitudinal, Normal, and Lateral axes. Unlike the automobile, our airplane is free to move about any one or all of these three axes. Thus it can roll (about the Longitudinal axis), it can pitch (about the Lateral axis) and it can yaw or steer (about the Normal axis).

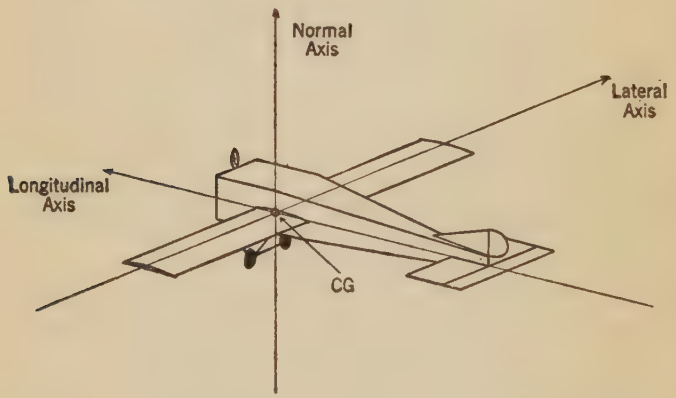


FIG. 11.

In order that the machine may be flyable at all, it must be controllable by the pilot about each of these three axes. However, because of the irregularities of the atmosphere, the airplane must also be so designed that it will independently resist external disturbances. And it is just here that the most remarkable results of modern aeronautical engineering have been achieved.

If the reader will imagine for a moment how the

seagull or the eagle, or any other of the large gliding or soaring birds, maintains its graceful flight over the edge of the cliffs or the masts of a passing ship he will gain a striking idea of the problems which have had to be overcome in order that the steady flight of an airplane might be achieved. The bird has feeling in its wings and in its tail so that a gust tending to turn it over sideways or alter its direction of flight against its will, is instantly detected by the bird and corrected accordingly.

The reader will at once realize how colossal has been the problem of artificial flight. The pilot has no means of "feeling" the presence or approach of a disturbing gust. It is not until the gust has had its effect upon the airplane that the pilot of the machine is aware of what has happened, and perhaps is still going on. Yet, in spite of what have seemed insurmountable difficulties, modern aerodynamics have developed methods applicable to aircraft design whereby the airplane is given a degree of inherent stability which in some respects even surpasses that of the eagle and the seagull. The achievement of this inherent stability in an airplane has called for the application of some of the highest mathematics which have ever been applied to the solution of any practical problem. Yet, even the stability of airplanes, in spite of the higher mathematics involved, can with careful treatment, be put into simple language such that the lay reader can understand.

Because of the inherent instability of a cambered wing, we have already seen the necessity for plac-

ing what we call a tailplane or "stabilizer" at the rear of the airplane body (known as the "Fuselage"). In this way we have secured stability about the Lateral axis; in other words stability against pitching (see Fig. 11). Furthermore, by means of small flaps attached to the trailing edge of the tailplane we have given the pilot control about the same axis, enabling him to climb or dive his airplane.

Let us see now what we require in order to provide for stability about the Normal axis. In an effort to provide the pilot with power to steer his airplane just as he can climb or dive it, we have already added a rudder. This will undoubtedly serve the purpose, but without stability the rudder control would be of comparatively little value, for if the rudder were once applied it is doubtful if the airplane would ever stop turning before it got out of control entirely.

In order to prevent this we must give the airplane an adequate degree of what might be called "weathercock" stability. That is to say, our flying machine must possess an inherent tendency always to fly into the wind. Of course, a weathercock is supported and rotates about a pivot. In the case of the airplane, however, we must consider it to be supported at, and even pivoted about, the Center of Gravity (see Fig. 11). In order that it may act as a weathercock and always turn into the wind, it must have more vertical area behind the Center of Gravity than ahead of it. Accordingly, we must attach to the forward portion of the rudder a verti-

PLATE II.

The Dornier SuperWal twin-engine, 1300 horsepower ocean-going seaplane with cabin accommodation for 21 passengers.

cal fin (shown triangular shaped in front of the rudder in Fig. 11). This extra fin and the fin area of the rubber itself, will force the tail to swing around and turn the plane into the wind unless prevented from so doing by the use of the rudder.

Following Fig. 12, let us assume the airplane flying straight ahead in the direction of the arrow (A). A lateral gust strikes it and causes the machine to turn about its Normal axis and veer off its correct course, taking up a new course indicated by the dotted position of the airplane and the arrow (B). Owing to the momentum which the machine possesses in the direction (A) at the moment of being struck by the Lateral gust, its new direction will not immediately be along the arrow (B), but rather somewhere between that direction and (A), namely, along the arrow (C). Obviously, then, if the airplane is in the position shown by the dotted lines but is traveling along the direction (C), there will be a lateral wind force on the left side of the plane. Since the machine has more fin area behind the Center of Gravity about which it turns than ahead of this point, there will be a force (D), known as a restoring force, acting upon the rudder and fin which will instantly tend to return the plane to its original position pointing in the direction (A).

Consequently, if, in addition to a rudder for steering, we provided the airplane with a fin surface of adequate size (thus giving the plane more side area behind the Center of Gravity than ahead of it), we

shall secure perfect directional stability and the pilot will not be concerned with side gusts except if these are extremely violent and the restoring force is insufficient, in which case the rudder will have to be employed. Without such directional stability it

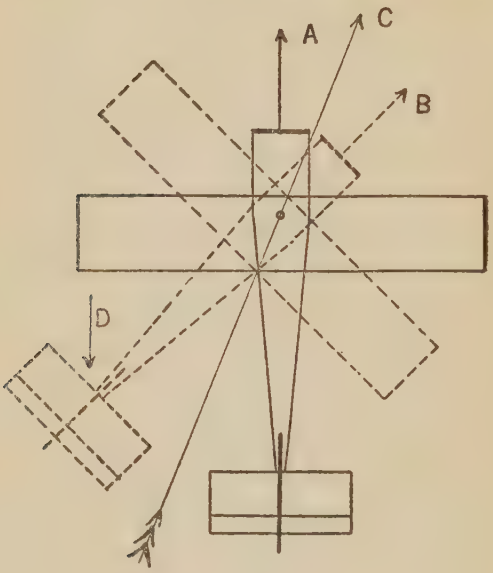


Fig. 12.

would be utterly impossible for an airplane to maintain a straight course. The first side gust which struck it would start it yawing and in the absence of a restoring force (D), the airplane would continue to yaw and would eventually be spinning around entirely out of control.

We have thus achieved in our airplane longitudinal stability by means of the tail plane, and directional stability by means of the vertical tail fin. We have yet to secure lateral stability, or stability about the Longitudinal axis, and then we shall have developed an adequately stable airplane and the only remaining problem will be complete control.

Lateral stability is without doubt the simplest form to be secured in an airplane. Its purpose is to prevent the machine rocking and rolling in flight and to counteract the rolling effects of lateral gusts. It is achieved by a very simple modification of the wing structure of the airplane itself, based upon the fact that the Lift of a wing is proportional to its effective horizontal area.

In the upper diagram of Fig. 13, the airplane is shown flying ahead horizontally. Since the Force of Gravity acts vertically, the Lift on the wings, which overcomes Gravity, must also be considered to act vertically. Accordingly, for the purposes of discussion, it may be said that the Lift on each side of the wing is proportional to the projected lengths of the semispans, AB and AC which we shall call "horizontal equivalents." Now suppose that the airplane meets a side gust which tends to roll it laterally about its Longitudinal axis into the position of the lower diagram (Fig. 13). It will be seen that, due to the rolled position of the airplane, the horizontal equivalents of the semispans of the wing will have been shortened. However, it will be seen that their lengths are still equal (AB=AC), and consequently,

the Lift on each side of the plane is the same, and it could continue rolling.

Now, let us give to the wing what is known in aeronautical engineering as a Dihedral Angle. That is, we will so arrange the wing of the airplane that its two halves slope upward from the fuselage, as in the upper diagram of Fig. 14. In so doing we shall have sacrificed a small proportion of the Lift

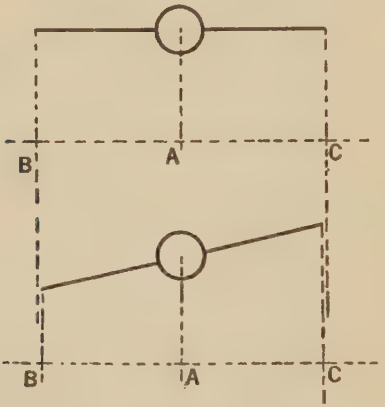


Fig. 13.

of the wing since it will be seen that we have slightly reduced the horizontal equivalents. This, however, will not be serious, especially when it is seen that in giving the wing a Dihedral we have secured the degree of lateral stability desired.

Suppose that the airplane represented in Fig. 14, is struck by a lateral gust which rolls it over along its Longitudinal axis into the position shown in the lower diagram. A mere glance at the new hori-

zontal equivalents AB and AC will reveal the fact that the Lift of the depressed wing is considerably greater than that of the raised wing. In other words, AB is greater than AC; the horizontal projected area of the lower wing is greater than the projected area of that which is raised, with the result that there is a restoring force brought automatically into play which tends to counteract the effect

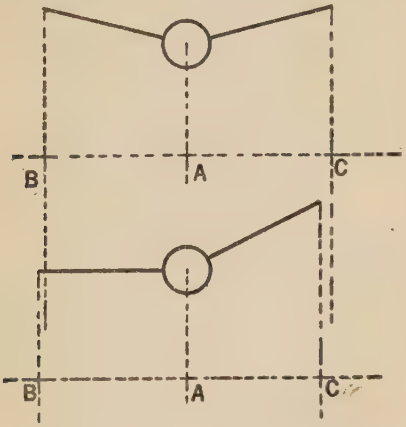


FIG. 14.

of the gust and bring the plane back to normal position without any effort on the part of the pilot. Of course, it should be realized that this stabilizing action and the bringing into play of the restoring force takes place within a very short space of time and the tendency for the machine to roll over sideways is counteracted almost before it has started. This is true of all the inherent stabilizing actions which have been discussed.

Let us now take stock of what we have secured in our airplane. In the first place the machine is inherently stable about each of its three axes. That is, it will of its own accord resist and correct disturbances which tend to throw it off its flight path and put it out of balance. In addition, we have provided longitudinal control through the fitting of elevators to the tail plane. These have the effect of depressing or raising the tail and thus altering the Incidence of the wing with increase or decrease of Lift, and the resultant climb or dive.

Lastly, by means of a vertical flap or rudder fitted to the fin which gives us our directional stability, we have provided a means whereby the pilot can steer the airplane. Here, however, we are going to run into difficulties. Flying at high speeds, as all airplanes do, were the pilot to use the rudder with a view to making a turn it is obvious that the forward momentum of the plane would throw it far off its course in a great sideslip, much in the same way as our automobile would sideslip off the road on a wet day were we to attempt to take a corner too fast.

In an airplane, however, owing to the thin medium in which it is immersed, no flying speed is slow enough to permit a turn without sideslipping, unless some special precaution is taken. Just as the friction of the wheels of a car prevents sideslipping on corners, unless the speed is excessive, so friction or resistance will prevent sideslipping on turns in the air, and obviously the wings of an airplane are

the logical means of providing a resistance of the right kind.

Accordingly, the pilot is provided with a control whereby he can, on turns, bank his airplane over and thus present the entire undersurface of the wing to prevent sideslipping. Banking is achieved by means of small flaps made in the wing tips on each

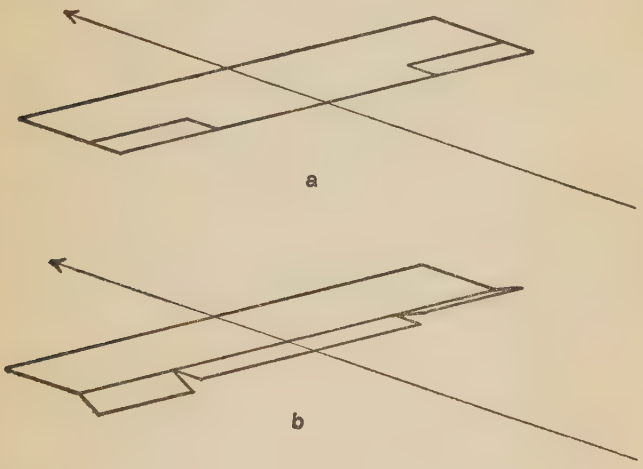


Fig. 15.

side of the fuselage as shown diagrammatically in Fig. 15, a. Obviously if one of these flaps is depressed it will cause an increased pressure upon the lower surface of that wing tip and, consequently, an increase in lift on that side will result.

This is the system adopted of giving the pilot lateral control over his airplane and enabling him to bank it on turns and prevent sideslipping. The

wing tip flaps are called "Ailerons" and are so connected to the pilot's control system that when one flap is lowered the flap on the other side is raised. Thus, the Lift on one wing tip is increased, while that on the other side is decreased, with the result that the airplane heels over laterally in a graceful turn.

Having now secured complete stability and control, the next problem to be studied is one of efficiency, in which questions of economy in power required for flying and simple structural problems will have to be considered. Our airplane already has a wing, but we have not decided what size and shape it is to be, nor do we know where to place it on the fuselage. There are still questions to be answered even though we have studied some of the basic problems.

CHAPTER III

The Complete Design

While it will have become very apparent at this stage of our study of the theory of flight, that the problems involved are, in reality, of the simplest, nevertheless it cannot be denied that the multiplicity of the factors which enter into the makeup of a modern airplane is little short of astonishing, as is also the almost remarkable manner in which these are co-ordinated. In studying the theory of flight, we have developed the airplane to a point where it would appear that all of the requirements have been fulfilled. We have provided Lift to overcome weight, and power and Thrust to overcome Resistance or Drag; we have built into our airplane a degree of inherent stability, and have given the pilot means for control.

However, like all mechanical contrivances, airplanes, in order to function satisfactorily, need efficiency. Moreover, since the flight of an airplane calls not only for dynamic propulsion but also for dynamic sustentation—being in this respect unlike any other mechanical vehicle—the quality of efficiency is of greater importance in the design of an airplane than in any other engineering problem.

In the case of the airplane, efficiency is more than just economy in power required for flight, even though in the long run it boils down to this, since one could make a serving tray fly if sufficient power were put behind it. Efficiency in flight means that every component part of the airplane must be reduced to a condition in which it is performing its function to the utmost. In this way the resultant combination will of necessity be efficient from the standpoint of power expended, and this, after all, is just what we are after.

Let us consider first the wing of our airplane, since this is responsible for the main factor in flying, namely, Lift. It is obviously necessary for efficency that our wing provide the maximum amount of Lift with the minimum amount of Drag. This may be expressed in another way by saying that our wing must have a high ratio of Lift to Drag; in other words, what is termed, in aeronautical parlance, the "Lift/Drag ratio" for the wing must be high. This problem had our consideration in part when we were developing our wing section from the purely theoretical standpoint. Now that we have reached the stage when we are about to put our airplane together and obtain the finished product, we must, however, consider the more practical aspects.

Having chosen a cambered wing section which gives a high Lift and a low Drag it will obviously be necessary for us to so construct our wing that the greatest advantage of the merits of this section will be obtained. For example, we must ask ourselves:

PLATE III.

The Pitcairn Mailwing, a high performance night mail plane used on a number of air mail services in this country. The engine is a 225-horsepower, Wright Whirlwind air-cooled type. The payload is 500–600 lb.

"Having decided how large a wing we need to lift the weight, is this to be made square or rectangular?" And again, "What shape shall we make the ends of the wing (called the 'Wing Tips')?"

In the first place, since the Lift of a wing, as we have already seen, is due to the reaction upon it of the passing air, obviously the Lift is proportional to the quantity of *undisturbed* air which is acted upon by the wing. That is to say, the more *undisturbed* air deflected downward by the wing, the greater will be the Lift. Obviously, then, it is the front portion of the wing which is the most important, since it is this part of the wing which does the initial deflecting of the air, the after portions merely holding, as it were, the air to its deflected path. From this it will be apparent that for a given area, the wider the wing, the more undisturbed air will be affected and the greater will be the useful work performed upon the air by a given area. Therefore our wing must be rectangular in shape and the greater its Span to its Chord the more efficient will it be. This ratio of Span to Chord is known as the "Aspect Ratio" of the wing, and the higher its value the greater the efficiency (see Fig. 16).

Again, we can consider other questions which enter into the plan-form of our airplane wing. As we have seen earlier in our study, the air appears to have a distinct objection to flowing past a wing, or, for that matter, past anything which gets in its way, and this is why we design our wing to offer the least possible resistance to the air (so as not to pro-

voke it too much). In Fig. 17 at (A) we have shown the course taken by the air flowing past the under surface of a square-shaped wing. It will be seen that in its inherent tendency to avoid passing the obstruction, the flow spreads out from the center and escapes as much as possible around the edges. Obviously there is a large dead space at the rear

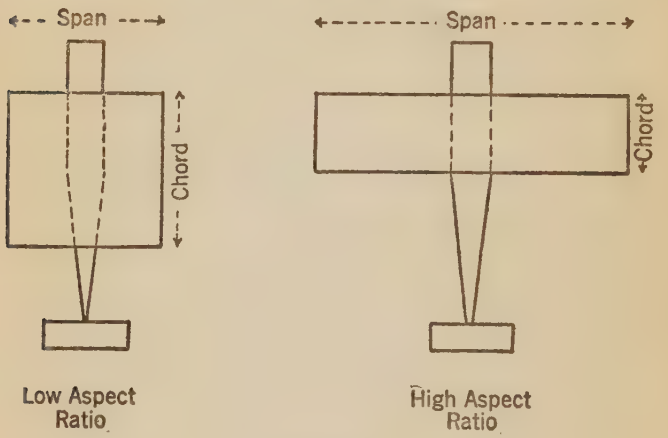


Fig. 16.

portion of the wing in the center which is not, therefore, doing its fair share of work in lifting.

If, however, we take the same area and dispose of it in a different way so that the wing has a higher Aspect Radio (Fig. 17, B), it will be seen that much of this problem will have been overcome. There is, however, still a tendency for the air to flow out from under the wing tip and this obviously represents a loss of Lift. In fact, there is far more in

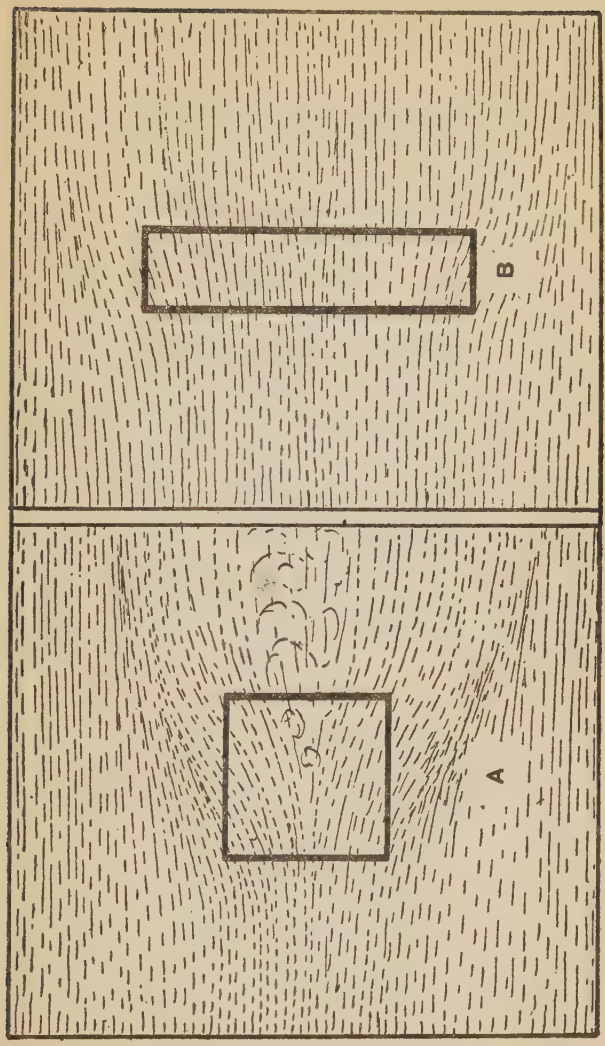


Fig. 17.—The effect of Aspect Ratio; note the spreading out of the streamlines around the wing tips.

this wing-tip loss than is at first apparent. It must be remembered that over the upper surface of the wing there is a marked suction, so that any air flowing out from under the wing tip will be sucked in over the top surface and will completely ruin the efficacy of the suction for a considerable distance in from the tip, as will be seen in Fig. 18.

To overcome the wing-tip loss the airplane wing can be "raked," to use the aeronautical expression.

Fig. 18.

This means that the trailing edge of the wing is made longer than the leading edge, with the result that the wing has the plan-form shown in Fig. 19, A. From the lines of flow it will be readily apparent that this change just about solves the problem of end loss. However, in order that we shall not be misguided and wonder why we do not see more airplanes with wings of this shape it should be added that because of the very high pressures which have been found to exist over the trailing

portion of the wing tip, the raking is usually modified to eliminate the sharp angular trailing corner, as in Fig. 19, B.

We are now almost ready to announce our airplane as complete and ready to fly. In our enthusiasm, we may possibly have been persuaded to believe that the machine was ready for flight long ago, but it is hoped that it has now been realized what a tremendous number of factors enter into the theory

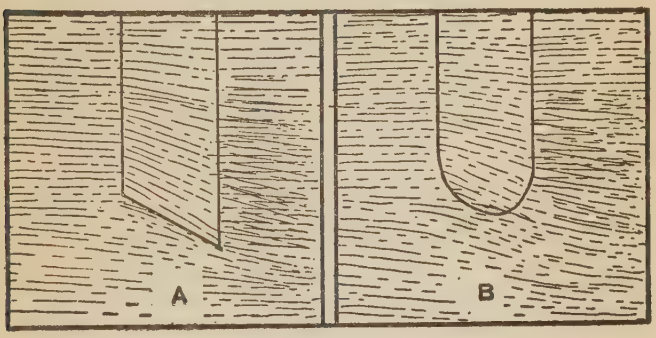


FIG. 19.

of flight and the design of an airplane. Having designed our wing so that it not only has a good cambered section but also has a nice high Aspect Ratio and raked wing tips, we have only to fix it to the body of the airplane in the correct place and then we are ready to consider how to make the body itself more efficient, after which we are really through. Only someone is sure to ask: "What about biplanes?" and then we shall appreciate that while we have gone a long way with this complex

problem we still have further to go. Like all complicated things, however, they can always be expressed simply.

In settling the final questions which arise let us first see how the fuselage itself, which after all contributes in no way to the flying qualities of the airplane, merely serving as a housing for the engine, the tail and the occupants of the machine, can be made more efficient. In other words, if we can reduce its Resistance or Drag we shall have gone a long way in improving the overall efficiency of the airplane, since we shall have accomplished a reduction in overall Drag with a corresponding increase in Lift/Drag ratio for the complete airplane.

Earlier in our study of the theory of flight we learned a little about streamline flow and the need for what we have termed "streamlining," in an effort to reduce the Drag of a body moving through air. Yet, so far we have given no consideration to the application of streamlining to the fuselage of the airplane, and that there are wide possibilities in this connection is evident from Fig. 20, A, which shows in side elevation the streamlines passing the fuselage with which, until now, we have been satisfied. Of course, in endeavoring to reduce the Drag of the fuselage we shall have to compromise in order to secure the necessary form for lowest resistance and still maintain the necessary size and space for engine and occupants.

Thus, for example, we will maintain as small a nose to the fuselage as reasonably possible in order

not to impair propeller efficiency. To include the engine, however, it will be necessary for us to give careful attention to streamlining around the cylinder heads, and to fairing the body lines off into the

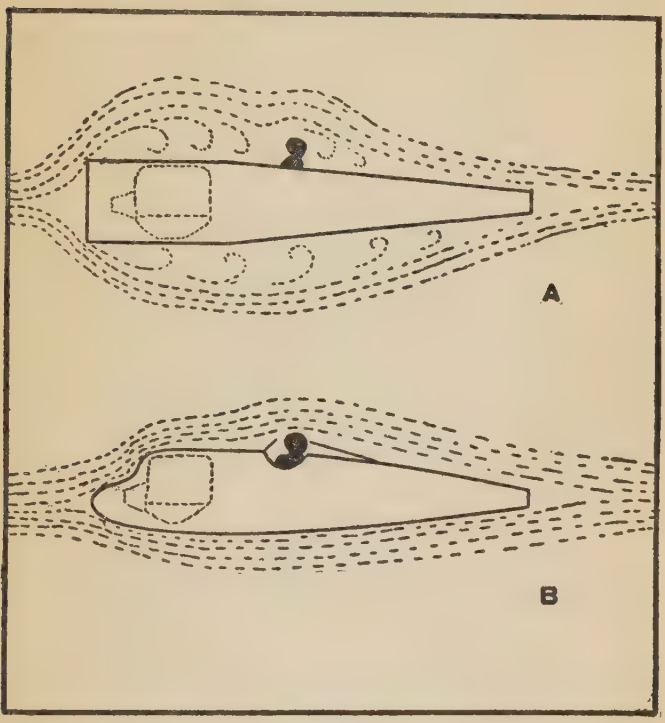


FIG. 20.

pilot's cockpit, which must, of course, be cut away, but which, nevertheless, must be so arranged as to reduce to a minimum the resistance of the pilot's head and the heads of passengers, in the event that it is a passenger plane. These requirements have

been carried out in Fig. 20, B, which shows the improvement that can be effected in Drag by streamlining.

Furthermore, in keeping with our effort to reduce the Drag of the fuselage, we must also consider ways and means of minimizing the resistances of struts and wires in the undercarriage, etc. These lend themselves to streamlining in every way as will be seen in Fig. 21 which is self-explanatory after what we have already learned about streamline flow.

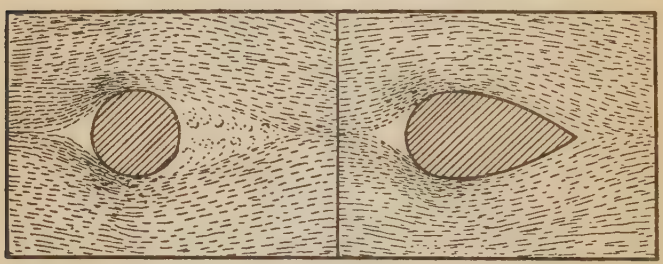


Fig. 21.

We shall not only streamline our struts in this way but also the bracing wires in our airplane, and in this connection it is interesting to know that, so important are these factors, there are in the aircraft industry companies which specialize in making streamline tubes, and others which make a specialty of streamline wire of all sizes.

Now, having "cleaned up" the component parts of our airplane for maximum efficiency we are in a position to think about assembling and balancing it, after which it will be ready to fly.

In looking for a solution to the problem of balance in our airplane we must remember that the factors involved are, (1) the vertically downward pull of Gravity through the Center of Gravity; (2) the vertically upward force of Lift through the Center of Pressure; (3) the horizontal Drag force which acts through a point around which all resistance forces center; and (4) the propeller Thrust which counteracts the Drag.

Accordingly, in the first place, we shall have to know accurately where the Center of Gravity of the airplane is going to be, in order that the wing can be placed in the correct position for balance. This position must be such that, when the engine is on, the airplane balances in the horizontal flight position. Again, it must be such that when the engine is turned off and the pull or Thrust disappears, the machine will of its own accord take up its natural minimum gliding angle, which may be described as the minimum angle of descent at which the airplane will fly without the wing Stalling.

To satisfy this condition, the Center of Gravity will have to be a little ahead of the Center of Pressure of the wing, so that the nose of the plane tends to drop immediately the Thrust is lost (see Fig. 22). However, this necessitates that when the engine is running there be a force tending to prevent the nose from dropping. This is achieved by placing the axis of rotation, or shaft, of the propeller, and consequently the Thrust line, below the center line of resistance (the imaginary line about

which the total resistance of the airplane centers). It will be seen from Fig. 22 that this condition, too, has been complied with, and our airplane is, therefore, balanced as far as general requirements are concerned.

For purposes of lateral stability we must remember to give the wing a Dihedral Angle, and we must certainly not forget that a Longitudinal Dihedral Angle between the wings and the tailplane is necessary for fore-and-aft stability. This means that the

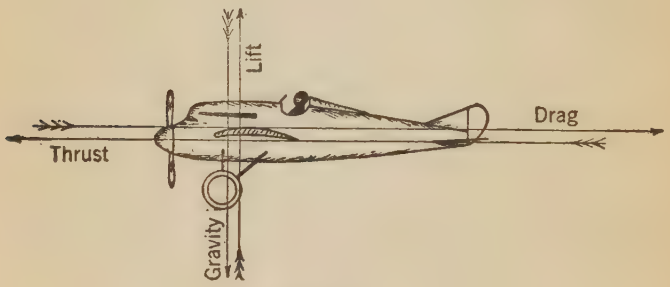


FIG. 22.

tail must be set at a smaller angle to the direction of flight than the wings.

These adjustments made, our machine is ready for the air. Thus, after a long journey through the very depths of aerodynamic theory, during which we have cheated the mathematician on all sides by arriving at the same conclusions without delving into the complicities of the science of numbers, we have succeeded in developing, from fundamental facts, the airplane. We have seen that, in spite of

the apparent flexibility of the air we breathe, we can so harness it that it is as a rigid roadbed to the airplane wing upon which we can fly to all corners of the earth without limitation or danger.

Our first airplane has turned out to be a monoplane simply because, for the purposes of discussion, it is a simpler type of airplane. We are now in a position to extend our studies further afield, for we have learned the essentials, and from these it is possible to build up indefinitely in this youngest of all engineering developments—AVIATION.

CHAPTER IV

How an Airplane Is Built

Without doubt the greatest problems which have to be solved by engineers in all fields of engineering work are those which enable the practical realization of the requirements of theoretical considerations. For example, the proposition may be one of spanning a certain river so that traffic may take a short cut. In essentials, nothing could be simpler—merely a bridge to be built. But the engineer is more concerned. He has to know the volume of traffic which will pass over the bridge per hour, the speed with which it is desired to deliver the traffic across the bridge, and a number of other things. From this data he is able to decide upon the type of bridge he will construct and the physical qualities which it must possess.

The problem of the aeronautical engineer is similar. We have already gone in detail into the theory of flight and we will probably have been impressed with the marked simplicity of this theory. There is nothing complicated in why the airplane flies, nor are the methods of satisfying the many requirements which enter into this theory difficult to understand. But when it comes actually to de-

signing and building the structure which is to put this theory into practice the possibilities of modern engineering are severely taxed.

There is no more complicated phase of engineering than that involved in aircraft design. This will be fully realized when it is pointed out that the airplane structure must be strong enough to withstand extremely severe and sometimes almost indeterminate loads, while at the same time being characterized by its light weight. Furthermore, the very nature of an airplane demands compactness of construction which does not in any way help matters. The quantity of equipment which the airplane designer is called upon to squeeze into his aircraft structure constitutes one of his major problems, while the necessity for lightness, accessibility and, above all, strength by no means simplifies this problem.

However, engineering has never yet failed to accomplish all that it has set out to achieve and so we find aeronautical engineering advanced to a point where, in the modern airplane, the theoretical factors of aerodynamics which we have already studied are brought into complete conformity with the practical requirements.

Let us see how this has been achieved. We know that our airplane needs a fuselage, wings, a tail and an undercarriage. We have learned the functions of these several units so that we are in a position now to start putting together our structure. In the first place we must decide what type of air-

plane we are going to build. This will depend very largely upon the purpose to which it is to be put. For example, is it to be a monoplane or a biplane (the former has one wing divided by the fuselage while the latter has two superimposed wings); a land type plane or a seaplane and if the latter, a float or pontoon seaplane or a flying boat? For the present we had better confine our attention to a small, simple type of plane, a land machine, which we can later learn to fly ourselves.

The first question which we should decide is whether our plane is to be a monoplane or a biplane. While this is primarily an aerodynamic problem it resolves itself into a question of structural engineering, since from the standpoint of flying qualities there is little to choose between the two types. Obviously, for an airplane to have a given lifting capacity it must have a certain wing area, other things being equal. Furthermore, we have already seen that the wing must not be square but rectangular, the greater the ratio of Span to Chord, in other words, the greater the Aspect Ratio, the more efficient the wing. This introduces structural complications for the greater the Span of an airplane wing the harder will be the problem of obtaining the necessary strength and rigidity. Therefore, whatever we do we must keep the span of our airplane wings as short as possible commensurate with efficiency.

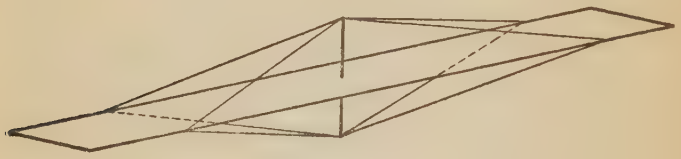
Since, however, the Lift of a wing depends upon the speed, we must not make the wings too small

or we shall have an airplane which is dangerous because the minimum speed at which it will fly is too high for safety. Accordingly, we have to compromise and after deciding the area of wing necessary we must give it as high an Aspect Ratio as possible without running into structural complications. It is here that the decision as to monoplane or biplane has to be made.

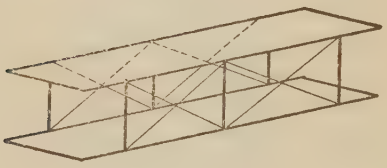
For a given area, obviously a monoplane wing will have a much wider span than a biplane wing, provided that a good Aspect Ratio is maintained, since in the biplane the required area is split up between two wings. Apart from the difficult housing problem for a plane of wide span there are also serious structural problems in building a very wide monoplane as will be realized from Fig. 23, a. In order to maintain adequate strength in the outer extremities of the single wing it would be necessary to build an elaborate bracing system to stiffen the structure or else a very thick wing would have to be employed. On the other hand, if the wing area is divided up and a biplane structure employed, considerable simplicity is achieved and it is possible by means of suitable interplane struts and wires to brace up the wing structure, so that a high degree of strength and rigidity is obtained, Fig. 23, b. From this it must not be assumed that monoplanes are inferior to biplanes because under certain circumstances, the monoplane employing thick wings is far superior to the biplane. For our particular purpose, however, the biplane is undoubtedly the

better and we will consider the construction of the machine along this line.

In early days all airplanes were made of wood, largely bamboo, covered with cloth. Now, however, with the greatly increased knowledge of the relative strengths of different metals and the development of methods of working metal, the use of metal



a



b

FIG. 23.

in aircraft construction has grown, until today we find all aircraft, without exception, incorporating metal parts and many constructed entirely of metal.

A light alloy of aluminum has been developed which, while having the light weight of this metal has the strength of mild steel and is, therefore, very suitable for aircraft work. However, this alloy, known as "duralumin," cannot be welded, since the

heating would disintegrate it and ruin its strength properties. Therefore duralumin, when employed in aircraft construction, is always riveted. Steel, however, can be welded, with the result that construction is greatly simplified so that this material, too, is used extensively in airplane construction. The extra weight of steel, while being a disadvantage in many respects, is not so serious as to render its use impossible.

With these few general comments upon materials used in aircraft construction, we are in a position to proceed with a consideration of the structure of our airplane, which is to be a low-powered three-place open cockpit biplane machine of modern design, suitable for private flying. Such a machine will have a welded steel tube fuselage, fabric covered, and will be fitted with wings constructed of wood—also fabric covered. The reason for using wood for the wing structure is that, weight for weight, a wood structure is considerably stronger than a steel structure, and while duralumin and even steel wings are in use, for a small machine such as we are building, wood is far more suitable. There is another point to be remembered, namely, that an airplane wing should, for strength, have a certain degree of flexibility, and this is adequately present in a wood structure.

We will first consider the construction of the fuselage of our airplane. There are four main members, called "longerons," extending the entire length of the fuselage (see Fig. 24). These

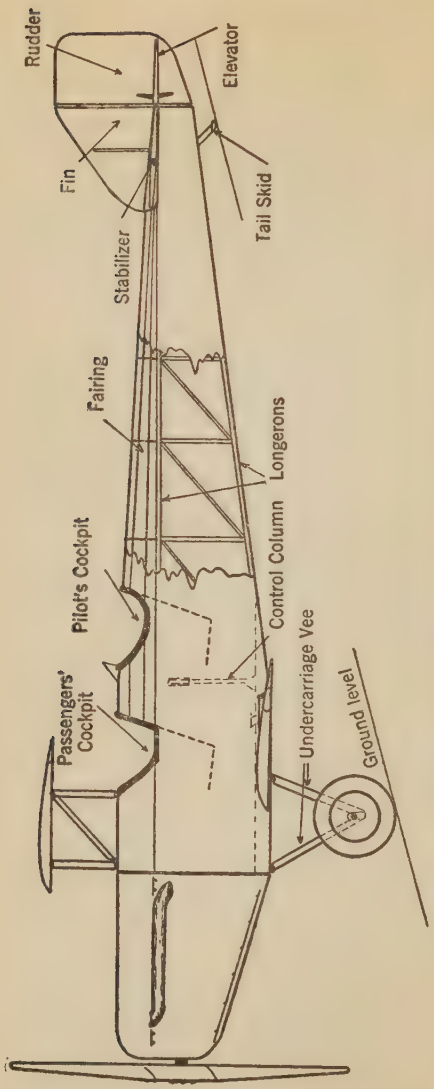


FIG. 24.—Showing internal fuselage construction and general layout of the airplane.

longerons, of steel tubing about one inch in diameter, are connected together by means of cross struts and smaller diagonal tubes for making the structure rigid. All of these steel tubes are welded together at the joints by an experienced man working an oxy-acetylene torch which has a flame of very great heat sufficient to create metallic union between the various tubes at the joints.

Seats—one in the rear cockpit for the pilot and a double side-by-side seat in the forward cockpit for the passengers—and all other internal fittings such as the pilot's instrument board to carry engine and flight-instruments, are assembled before the fuselage framework is covered.

After the whole structure has been painted or varnished as a protection against deterioration, the covering is put on. Cotton fabric is used and is stretched over the fuselage longerons and over the light wood or metal strips which extend along the sides and top of the structure for the purpose of fairing off the shape of the fuselage to reduce head resistance. In covering the fuselage, the various metal fittings for the attachment of the undercarriage struts and the wings protrude. The entire fabric covering is then impregnated with an especial cellulose compound which adds considerably to its strength and durability and also serves to stretch it taut over the framework.

The forward part of the fuselage is not fabric covered, aluminum sheeting being used to cowl the engine and the cockpits. Quickly detachable clips,

as in the case of the automobile, enable easy inspection of the powerplant, gasoline tanks (which are in the fuselage ahead of the front cockpit), etc. The powerplant, an eight-cylinder in-line Vee type water-cooled engine developing 90 horsepower is fitted, massive ash engine bearers being provided at the forward end of the fuselage for supporting the engine. Of course, there are other types of engines in use in aircraft as will be seen later, but the class of powerplant described is in common use in light three-place airplanes of the kind in which we are at this time interested.

The undercarriage consists of two Vee-shaped metal strut formations of streamline section steel tubing (for reducing head resistance) extending down from attachments on the two lower fuselage longerons under the passengers' cockpit. The axle, carrying the two wheels, is laid in the apex of these Vee's and bound to them with braided rubber cord, which is simply a ½-inch cord made up of strands of rubber wrapped together into a sort of rubber cable by means of twine braiding.

Binding the axle in place with rubber cord gives the undercarriage excellent shock absorption qualities for, when the wheels hit the ground heavily in taking off or landing, the axle will move up out of its seatings on either side, restrained only by the rubber cord which absorbs the shocks. Furthermore, the pneumatic balloon type tires of the wheels, which are similar to automobile wire wheels, also have marked shock absorption qualities and are very

PLATE IV.

The Pitcairn Fleetwing, a low-powered (90 hp.) three-place plane designed for the private owner.

necessary in an airplane running over uneven ground at anything up to 50 miles per hour (and faster in larger types) when landing or taking off.

The tail end of the fuselage is supported off the ground by means of what is called a "tail skid." This consists merely of a short stick of ash or metal extending out of the tail end of the fuselage in such a way as to hold the tail off the ground. It, too, is sprung with rubber cord so that it will absorb shocks on landing and taking off. The student may wonder why a wheel is not used at the tail in place of the skid, since obviously the former will run over the ground very much more steadily. It should be remembered, however, that in taking off, the tail of the airplane is raised from the ground at the earliest moment and the drag of the tail skid on the ground is, therefore, not present, while in landing it is very necessary that the tail skid should drag since in this way the landing run of the airplane will be reduced.

We have now considered the complete fuselage and undercarriage construction. The engine is in our airplane and is cowled. We have yet to discuss the construction of the wings and the tail unit, which consists of the horizontal stabilizer, elevators, vertical fin and rudder, and then we shall look over our airplane and learn how its various parts function.

The wings, as already indicated, are, in this type of airplane, made of wood, fabric covered, since this form has been found to be the most suitable.

Moreover, contrary to what might be expected by those who have not had occasion to know, the wood and fabric structure of airplane wings is a most durable form of construction, having many years of useful life before serious deterioration sets in.

We have already learned that, for maximum aerodynamic efficiency, the wings of an airplane are cambered, the curvature of the upper surface being markedly different from that of the lower. The framework of the structure is, therefore, more complicated than would be necessary in the event that a flat surface were employed.

Before continuing to a consideration of the details of the wings, it will be well to give some initial thought to the mechanical requirements which have to be satisfied. In the first place, their very nature would indicate that the wings of an airplane must be strong enough to carry the entire weight of the airplane in flight plus their own weight. Furthermore, they must possess a margin of strength, known as the "Factor of Safety," to take care of sudden loads which will be imposed in flight due to an outside disturbance such as a wind gust. Again, at the termination of a dive, when the pilot flattens out into level flight once more, there will be a greatly increased apparent weight on the wings due to the downward momentum, just as one feels heavier upon one's feet when one reaches the ground floor in a descending elevator. All these conditions have to receive consideration in the building of the wings of our airplane.

Nor is this all. Not only do the wings of the machine have to stand up against greatly increased vertical loads such as those just described, but in landing, at the moment the wheels of the airplane touch the ground and the weight of the machine is taken off the wings, they must be strong enough in the other direction, namely, downward, to withstand the tendency to collapse at the moment that the relative upward force disappears.

From the foregoing, it will be seen that the wings of an airplane have to be unusually strong—not forgetting the everlasting call in aeronautical engineering for light weight. But the student should note that most of the loads imposed upon the wings are vertical, the horizontal, or backward loads being confined entirely to wing drag, which is an easy matter to overcome.

Now, with a thorough knowledge of what we want in our airplane wings, we can go ahead with our construction. The major members in the wing structure are the two main spars or beams which extend along the entire span of each wing panel. (See Fig. 25.) Since the major loads which these beams have to withstand are, as we have seen, vertical, these beams should in cross section be made deeper than they are wide, Fig. 26, a. But, with a view to saving weight it has been found possible to cut away from the sides of the beams quite a large amount of material without jeopardizing the "vertical" strength qualities of the beam, while the "horizontal" strength qualities are not serious enough

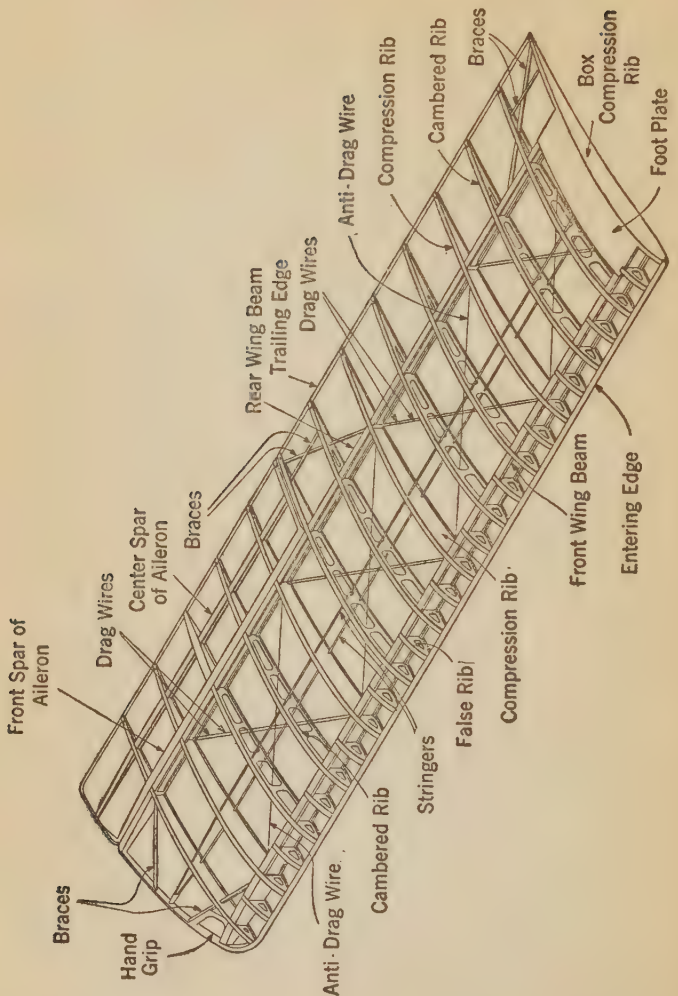

Front Spar of Aileron
Drag Wires
Center Spar of Aileron
Braces
Rear Wing Beam
Trailing Edge
Drag Wires
Anti-Drag Wire
Compression Rib
Cambered Rib
Braces
Box Compression Rib
Foot Plate
Braces
Hand Grip
Anti-Drag Wire
Cambered Rib
Stringers
False Rib
Compression Rib
Front Wing Beam
Entering Edge

FIG. 25

to enter into consideration in this connection. So we arrive at a beam with a section like the letter "I" (see Fig. 26, b) having great strength and lightness.

These spars, two in each wing, namely, a front or main spar and a rear spar, are made of especially selected straight-grained knotless spruce, which has

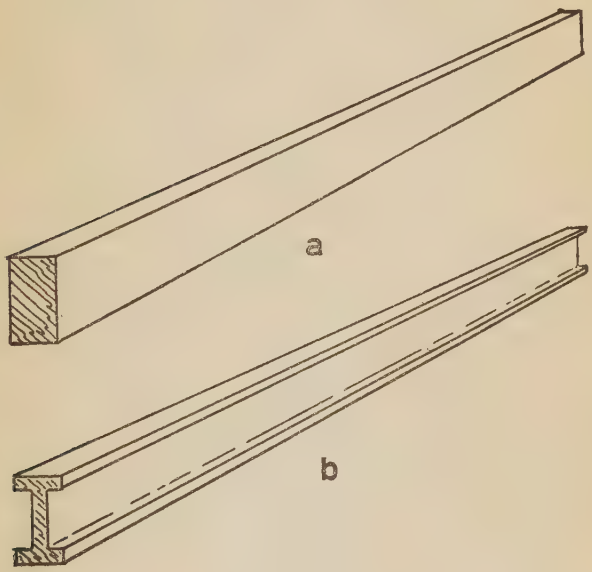


Fig. 26.

about the highest strength for its weight of all woods.

In order to secure the correct cambered section for the wing, ribs are used, spaced eight or nine inches apart along the two spars. These ribs are made up of three-ply wood which, consisting of thin

layers of wood glued together with the grains at right angles to each other, has considerable strength in all directions and cannot readily split. The plywood is cut out to the shape of the streamline wing section (usually a number of ribs are cut out at the same time to obtain uniform shape) and then the piece is cut up into sections, the leading section, the middle section and the trailing section. (See Fig. 27, a.)

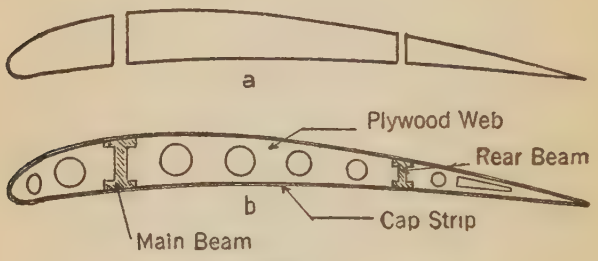


Fig. 27.

Two thin strips of spruce, called "cap strips," are placed along the top and bottom edges of the plywood rib sections, fastening them together into one unit but leaving spaces for the beams to pass through. (See Fig. 27, b.) The rib is now complete in essentials but the student will notice the holes which have been cut in the plywood. This is done for lightness, it having been found possible to save considerably in this way without impairing the strength of the rib. It may be pointed out that this is but one form of rib construction. Other forms of built-up ribs are in use but the general principle

of construction differs little between the various types.

The complete wing structure is now assembled. Ribs are threaded, as it were, onto the two spars and secured at the requisite distances apart with strong glue and nails. Between every two ribs there is placed what is known as a compression rib which is made a little stronger than the others in order to take the internal wire bracing loads or strains in the wing. An examination of Fig. 25 will reveal these compression ribs. It will also be noticed that leading edge forming pieces are inserted in order to keep the curvature of the fabric correct over the leading edge of the wing, for it will be recalled that the upper leading edge of the wing section is, aerodynamically, one of the most important parts of the wing.

It is now only necessary for the leading and trailing edge strips to be put on and the wing structure is complete except for wire bracing which, as will be seen from Fig. 25, gives the wing rigidity. The careful observer will notice that on this wire bracing all the drag wires, namely, those which brace the structure against the resistance forces in flight, are duplicated for safety. These are those wires which slope backwards and outwards.

If the particular wing panel under construction carries an aileron (some modern airplanes have ailerons on the lower wings only) then the outer trailing portion of the wing behind the rear spar will be slightly modified to allow for the movable

flap, as shown in Fig. 25. Furthermore, if it is a lower wing, a wooden footplate is fitted over a portion of the wing root for the purpose of facilitating climbing into and out of the cockpits.

The wings are now ready for covering as soon as the control wires, which we will discuss when we learn to fly the plane, have been fixed. The covering operation requires no discussion. Fabric similar to that used for the fuselage is employed and is stitched on and then doped until it is taut and strong.

We have now made the fuselage and mounted it upon an undercarriage; we have made the four wing panels and only have to rig these on to the fuselage, after which we must give some consideration to the tail unit which, however, is vastly more simple in construction than the main wings.

To simplify mounting of the wing structure and to gain rigidity and strength the upper wing panels are mounted on what is known as a "center section." This is a comparatively small length of wing structure made in much the same manner as the wings themselves and supported over the fuselage on struts (see Fig. 28). The center section serves the purpose of providing a firm structure to which the upper wing panels are attached at the roots just as the lower longerons of the fuselage are the anchorage points of the lower wing panels.

Metal fittings in the wing roots fit into similar fittings on the center section and lower longerons, respectively, and steel bolts secure the wings in

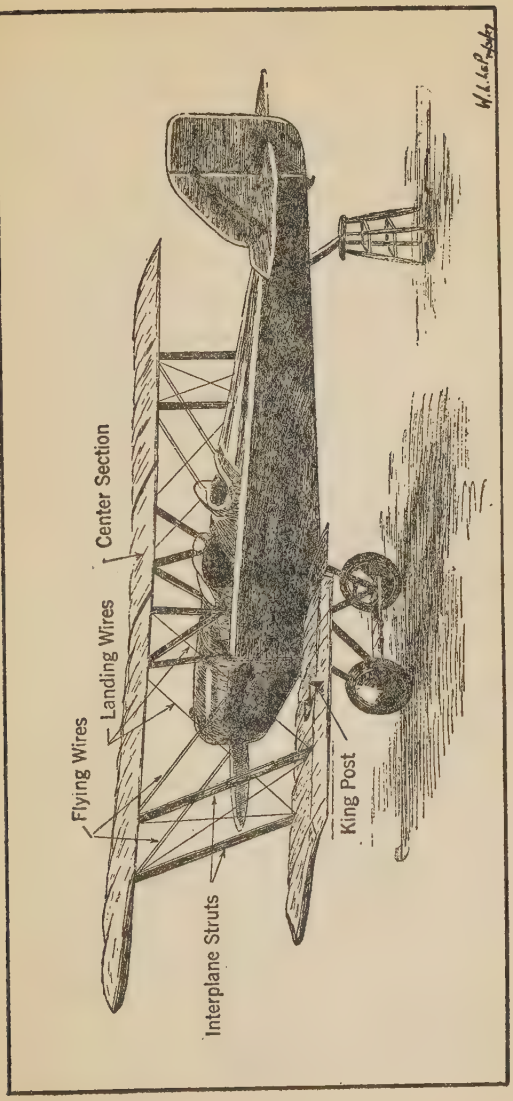


FIG. 28.—The complete airplane.

place, while the outer extremities of the wing panels are supported and separated by a pair of vertical struts on each side, known as "interplane struts." Usually the interplane struts are placed some few feet from the wing tips so as to equalize the lift stresses in flight over the unsupported parts of the wings.

There is another requirement, however, before the wing structure of our airplane is rigid and strong enough to carry the weight of the plane in flight. So far there is no provision for preventing the wings from swinging upward from the roots under the weight of the plane in flight or from flopping downward and dragging along the ground when landing. For safe flight the wing structure must have a high "factor of safety"—that is, it must be capable of carrying loads equal to five or six times the weight of the plane with its occupants in order that under no circumstances can there be a breakage under strain.

To secure this rigidity in the wings the entire structure is braced by means of very strong steel wires. A careful examination of Fig. 28, will reveal how this wire bracing of the wings is carried out and it will be observed that those wires which take the lifting stresses in the structure are doubled for safety. These wires, known as "flying wires," extend upward and outward from the lower wing roots to the upper extremities of the interplane struts. The "landing wires" which stiffen the wing structure against down loads on the wings such as

when the plane touches the ground on landing, cross the flying wires in a diagonally opposite direction.

Larger airplanes such as the big mail planes and passenger air liners of this country and Europe of necessity have a somewhat more elaborate bracing system. Many of them have more than one pair of interplane struts on each side because of the much wider span of their wings, but in all cases the fundamentals of the bracing system are the same. In other types of planes having cantilever wings, in other words, internally braced self-supporting wings, there is no outside wire bracing at all. Most of these types are monoplanes such as the Fokker plane used by Commander Byrd in his transatlantic flight. On the other hand, there have actually been a few cantilever biplanes constructed, although the comparatively simple bracing of a biplane structure, as we have already seen, tends to discourage the cantilever with its necessity for thick wing sections.

The tail surfaces are the next to be fitted. These include the stabilizer and elevator and the fin and rudder. These will be constructed of a welded steel tubing framework covered with fabric, impregnated, as in the case of wings and fuselage, with airplane dope. The framework of the tailplane surfaces is vastly more simple than that of the wings, for the tail surfaces require no special section of such exact curvature as do the main wings. All that is necessary is that the frames shall be strong enough to withstand the very high wind pressures experienced in flight when climbing or diving (in the case of the

stabilizer and elevators) and when turning (in the case of fin and rudder). Of course, suitable, though very simple hinges are provided to enable the movable surfaces, namely, rudder and elevators, to be operated by the pilot, small posts, known as "king posts," being fitted to take the wires which connect with the controls in the pilot's cockpit.

The stabilizer, because of the high stresses set up in flight, is braced by means of a streamline steel tube strut extending from each side of the vertical fin down to the main spar of the stabilizer on which the elevators hinge.

Our airplane has now taken shape and is ready for flight with the one exception that we have yet to bolt the propeller to the engine shaft. A special propeller hub is used, consisting of two circular plates drilled for seven bolts which pass through the boss of the propeller and secure it firmly to the shaft. In order, however, that we may fully understand the airplane structure in every detail it will be well for some brief consideration to be given to the construction of propellers in general.

Airplane propellers are made of wood or metal (usually duralumin, an alloy of aluminum) and more recently a composition known as Micarta has been used with success. Owing to the extremely high tipspeeds (the speed of the blade tips) of airplane propellers rotating at between 1600 and 1800 revolutions per minute, it is necessary that a material which will withstand very high stresses be

used. For this reason the woods adopted for propeller construction are most carefully selected.

A wooden airplane propeller is made up of five or six laminæ or planks each cut to shape and then secured one above the other in fan shape and tightly glued (Fig. 28, A). After having been put aside to set in a powerful press, the propeller is carved out to dimensions and finished in the usual way using high-grade varnishes. Propellers constructed in this way not only have great strength because of the differences in the grain formations of the laminæ of wood, but they possess long life in use. However, a wooden propeller has a real disadvantage in that it is liable to chip during a very heavy rain or sleet storm, the force with which the blades strike the drops of rain damaging the propeller very considerably.

This drawback is overcome in the metal propeller. There are three types of duralumin propellers in use today, namely, the twisted type, the forged type, and the adjustable blade type. The twisted type of duralumin propeller is made from a shaped slab of the alloy which is simply twisted to give the required blade angle. Blocks of metal are bolted on to form the boss and the propeller is ready for use. Needless to say the bending process has to be carried out with the greatest care, but the manufacturing process is obviously extremely simple.

In the forged duralumin propeller the process of manufacture is merely a matter of forging and finishing in the ordinary manner. However, owing

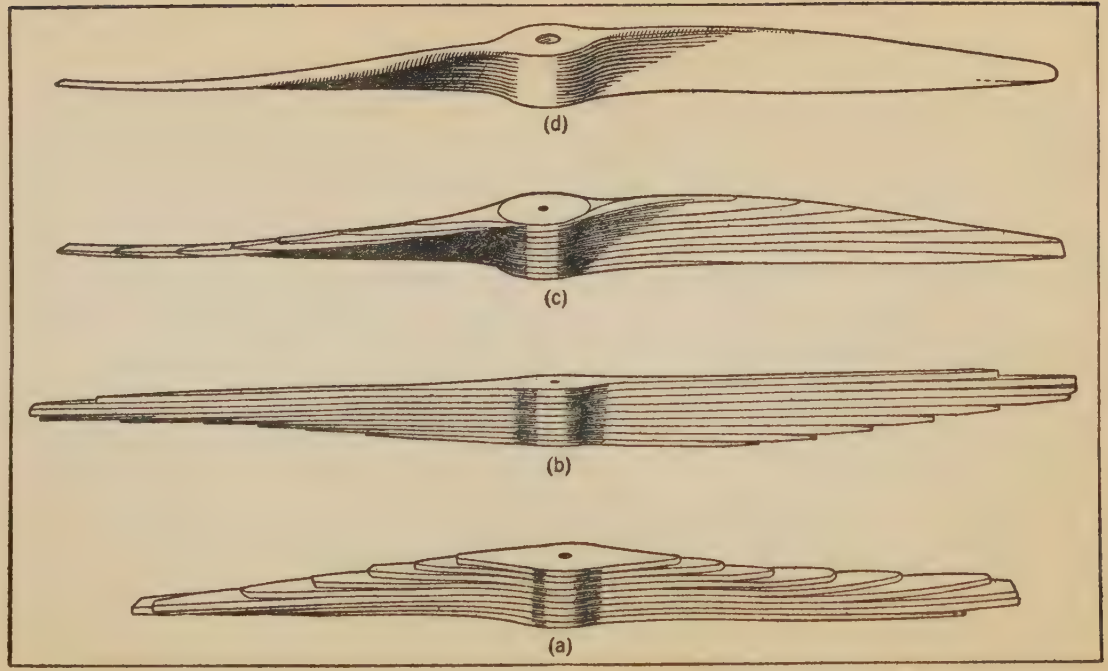


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FIG. 28A.—Four progressive steps in the construction of the laminated wood propeller.

to the necessity for preventing the decomposition of the alloy into its basic constituents, the forging process is one of the most difficult ever undertaken, and consequently forged propellers are most expensive and are used only by the air services and in special cases.

The adjustable blade metal propeller is similar to the forged type except that the two blades are made separately and fitted into a steel hub in such a way that they may be set at any desired angle and so the propeller suited to any engine. One of the problems with propellers of this type has been that of guarding against the possibility of the blades flying off the hub under the colossal centrifugal strains at high rotational speeds. This liability, however, has been overcome and propellers of this type are in extensive use by the navy and in commercial planes.

That a material such as Bakelite should ever find its way out of the world of electricity and radio may seem strange, but, nevertheless, we find this material being used more and more in the manufacture of Micarta propellers, which are nothing more nor less than pressed Bakelite reinforced with impregnated fabric. Micarta propellers are growing in popularity in commercial as well as in service aviation. Whatever type of propeller we choose for our airplane, however, it will be found possible to obtain from the manufacturers one suitable for our 90 horsepower engine. Having bolted it onto the

engine shaft, the plane is ready for flight, and after all we have learned about its theory and construction we should look forward to our first flying lesson with every confidence.

CHAPTER V

Flying Instruction

From what the student of aeronautics has already learnt of the subject, the problem of actually learning to fly should present no obstacles to him. He will find it no more difficult to pilot a small airplane than it is to drive a gear-shift car and in many respects flying will be found very much simpler. Furthermore, the student need have no fear for the safety of flying, since he has already learnt the factors which make flight possible and has seen how the airplane is designed to harness the air in such a way that nothing short of running into something (which is always likely to end rather sadly) or a possible structural failure in the air can cause single difficulty. So much is now known of the forces to which an airplane is subjected in flight that structural weaknesses in modern airplanes are unknown.

On the subject of safety, however, it might be pointed out that the hazard in all forms of transportation is dependent upon the conditions. Driving at 30 miles an hour or so in one's automobile in the snow is likely to be hazardous. Unless circumstances make it necessary for us to do such a thing we refrain from taking a ride when the ice is thick

over the roads. And so in aviation, too, it is when unnecessary risks are taken that trouble occurs. Straightforward flying in a modern airplane is as safe as pleasure driving in one's car. Recalling the limitless nature of the atmosphere, in fact, flying might be regarded as safer than driving for there is less possibility of a collision.

Flying is essentially restful. In a modern airplane it is possible, after pointing the plane in the right direction, to leave the controls indefinitely, adjusting them from time to time only to keep the machine on its course. In an automobile it is impossible to relax at the steering wheel. Of course, in an airplane there are three controls to manipulate, namely rudder, elevators and ailerons. However, just as starting a car involves operating the clutch with one foot, the accelerator with the other, the gear shift lever with one hand and the steering wheel with the other hand and this complicated operation becomes second nature, so controlling an airplane grows to be merely an instinct.

The student airplane pilot should make up his mind that he has got to fly by instinct before he can become proficient. Confidence, as in all other undertakings, even that of riding a bicycle or driving a car, is a primary requisite.

Before going up in our airplane with the instructor for our first lesson we had better clamber into the pilot's seat, which is in the rear cockpit and familiarize ourselves with our whereabouts, the controls, the instruments, etc. On the instrument

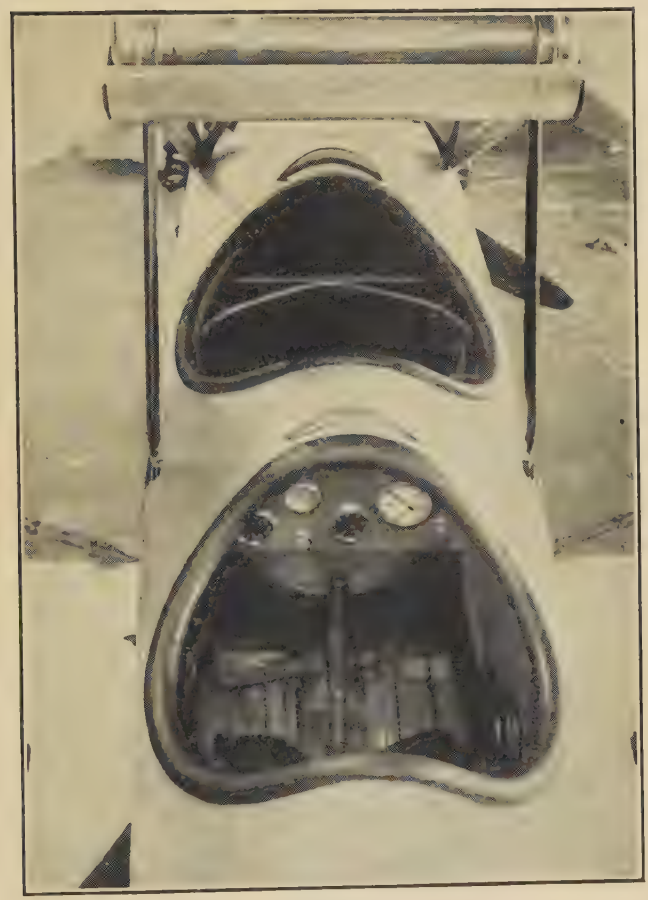

PLATE V.

View looking down into the pilot's cockpit of a small two-place plane. Note the top of the control stick and the rudder bar on the floor of the cockpit. The layout of the instrument board will also interest the reader. The forward cockpit (at top of picture) is for the passenger.

board in front we shall notice several round dials indicating different things. For instance, there will be a tachometer which will tell us how fast the engine is turning. This is one of the most important instruments since only by knowing how fast the engine is turning will we be able to tell whether or not it is running well, except that eventually we shall become accustomed to its sound and will be able to tell the instant something is wrong. Furthermore, as will be seen later, the tachometer will indicate to us whether we are rising or falling in flight and will thus serve as a check on other instruments.

Another instrument is a thermometer which indicates the temperature of the lubricating oil. There will also be an airspeed indicator, showing, as its name implies, the speed at which the airplane travels through the air. The indication of this instrument must not be confused with the "ground speed" of the airplane.

An airplane which normally flies level at, for example, 80 miles per hour will, when flying into a 20-mile per hour wind, have a "ground speed" (speed over the ground) of only 60 miles per hour. On the other hand, if the wind is following, the ground speed will be 100 miles per hour although in either case the air speed indicator will register 80 miles per hour. It is the air speed that primarily concerns the pilot for the air speed must not be allowed to drop below a certain figure or the wings will start to lose their lift. On the other hand, if

the air speed increases too much, as for example in a nose dive, the forces on the plane may become too great.

Other instruments on the dashboard of the plane might include the compass, and a turn-and-bank indicator, although neither of these is necessary for straightforward flying in fair weather in which the private owner is primarily interested.

Sitting in the pilot's cockpit, the student flier will observe the engine throttle, a small lever with a knob on it, located in a position readily accessible to the left hand. Pushing the throttle lever away from him, the pilot opens the throttle, while pulling it forward closes it.

Finally, we come to the airplane controls. Because he has seen nothing exactly like them before, the student is sure to express the thought that he will never be able to master them. However, he will soon see his mistake in entertaining any such feelings for the control of an airplane is eminently simple.

To take the steering first—at his feet the student pilot will find a horizontal bar with foot rests at each end. This bar, called the "rudder bar," is pivoted at its middle and the pilot can swing either end forward or back with his feet, as he pleases. If, when he is sitting in his seat, he twists himself around so that he can squint at the rudder out of the corner of his eye while he moves his feet he will see that pushing his left foot forward, for instance, will pull the rudder over to the left. That is, he will

see the left side of the rudder, which means that if he were flying, the tail end of his airplane would be pushed off to the right and, consequently, the plane would take a left turn. The effect would be reversed were the student to push his right foot forward.

It will be noticed that the airplane turns toward the side on which the rudder bar is pushed forward. The rudder control, therefore, is strictly natural, as are all the controls of the airplane. That is to say, the controls are arranged so that the motion which is most natural under any particular circumstance is the motion which must be made by the pilot to satisfy that circumstance. Thus, if the desire is to turn to the right, one of the most natural things for the pilot to do is to push his right foot forward, and this actually is the movement required for executing this maneuver in flight.

Turning now to the longitudinal control, namely, that which governs the rising and falling of the airplane in flight, the student will find the necessary movements equally natural. Coming up between his knees the student will find a vertical stick with a handle to it. Grasping this lightly in his right hand he will find that he can move it backward or forward and that it is pivoted at its lower end. Looking around again at the tail of the plane the student observes that when he pulls the stick toward him the elevators are pulled up. In flight, as we have already learned, raising the elevators results in a downward air force on the tail, depressing it

and having the effect of increasing the angle of incidence of the main wings, with the result that the airplane climbs. Pushing the control stick forward, reverses the action and the airplane in flight goes into a glide. Again it may be emphasized that the control action is a natural one.

By now, no doubt, the student will have discovered that not only can he move the control stick back and forth, but that it will also move to either side, and that the two motions can be combined. The sideways motion is for the purpose of securing lateral control with the ailerons. Moving the stick to left, for instance, will result in depressing the aileron or ailerons (depending upon whether or not there are ailerons on both upper and lower wings) of the right wings and raising those on the left wings.

As we saw when we were studying the theory of flying, the ailerons are for regaining the lateral level of the airplane in flight or for banking to prevent sideslip on a turn. The effect of raising the left ailerons and lowering those on the right is to lower the left wing because of what is in effect a decreased angle of incidence given to the left wing tip and an increased angle to the right wing tip. Moving the stick in the opposite direction would have the reverse effect. It will again be realized that the action is the one most natural to the pilot, for what could be more instinctive to the pilot wishing to lower the right side of his plane than for him to

move the control stick over toward the right, or vice versa.

The student will now have a very fair idea as to how the three controls of his airplane are actuated. The control system is operated by means of push-and-pull rods or cables and with the aid of the diagram (Fig. 29) he would do well to examine the system with care, so that he will be thoroughly conversant with every detail before going up for his first flying lesson, for which he is now ready.

A normal clear day should be chosen for the first instructional flight. In the early days of aviation, before airplanes were as easy and simple to fly as they are nowadays, all instruction was given very early in the morning, soon after daybreak, or in the evening at sunset. At these times the air is exceptionally calm and therefore suitable for novice flying. Progress, however, has changed this condition and one day is as good as another on which to learn to fly provided there is not a high wind blowing to make piloting a little more difficult.

The pupil will receive his flying instruction in a normal type of airplane equipped with what is known as dual control, a complete system of controls being provided in both cockpits. What a change from the early days of aviation when an airplane could barely carry its pilot, let alone carry an instructor aloft! In those hard, pioneer days it was a case of teaching one's self to fly by a system of trial and error or being satisfied to remain on

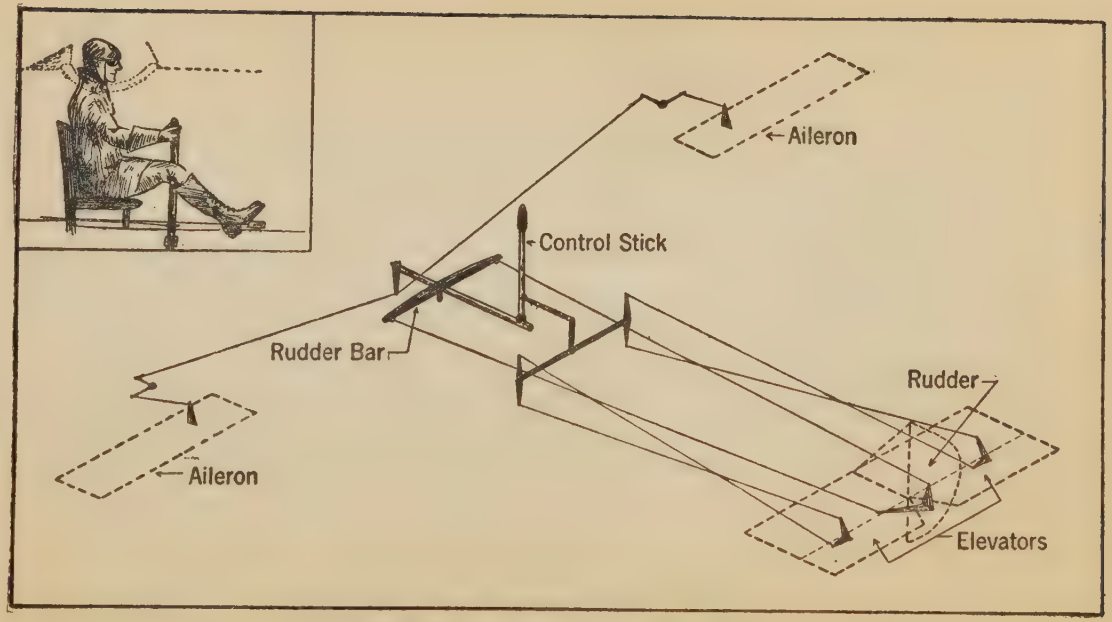

FIG. 29.—The airplane control system.

the ground and watch others. Then it was that a would-be airplane pilot had to master the take-off before he had acquainted himself with the simpler though still (in those days) somewhat hazardous problem of straight flight. However, the real problems of learning to fly in those precarious aviation days will be realized when it is recalled that from the moment of the first flight the self-taught student pilot was obliged to execute a landing—of some sort —perhaps even before he had fully mastered the art of straight flying. Hence the slow and frequently punctuated progress made. Furthermore, while the modern airplane will fly almost by itself, it would take all of the skill of the most proficient pilot of today to maintain balance and control in one of the skeleton-like airplanes of yesterday.

So it is with every feeling of assurance and confidence that we can step into the pilot's cockpit of the airplane, with our instructor seated in front and take off on our first flying lesson. The pupil will occupy the regular pilot's cockpit in order that he may gain the feel of the airplane in the right way from the start. Before him he will have the control column and rudder bar to which are connected also the controls in the instructor's cockpit so that if the student makes a mistake the instructor can instantly rectify it and demonstrate the correct procedure. Before going up the student will have been told by the instructor what to expect and when he is to take over the controls. A speaking tube connects between the two cockpits and permits a

one-way communication from instructor to pupil during the flight.

The time has come to start. The plane is pointing into the wind and the engine is turning over slowly. The instructor pushes the throttle lever forward and the engine roars to life. The plane rolls heavily over the ground at an increasing speed. A slight forward movement of the control stick pulls down the elevators a trifle and the tail lifts into flying position, thus reducing the head resistance of the plane and eliminating the drag of the tail skid over the uneven grass. The take-off is under way. The pupil should watch everything very carefully in order to gain some idea of what is necessary for a successful take-off. Quickly the airplane speeds across the ground, more and more of the weight being taken by the wings as the speed increases, until finally flying speed is reached and the airplane gently leaves the ground climbing slowly.

The details of the take-off will not be the major concern of the student until after he has mastered the control of the airplane in full flight so that we will not dwell further upon this stage of instruction except to say that a modern airplane takes off almost automatically, requiring the minimum of effort on the part of the pilot.

Having attained an altitude of around 1500–2000 feet and after having flown around for a while to accustom the pupil to flying (although it is assumed that he has already experienced flying as a

passenger) it will be well for the student to handle the controls and endeavor to get the "feel" of the airplane in the air. This should be done methodically, one control at a time, starting with the rudder. At the signal from the instructor the student pilot should place his feet on the rudder bar and,

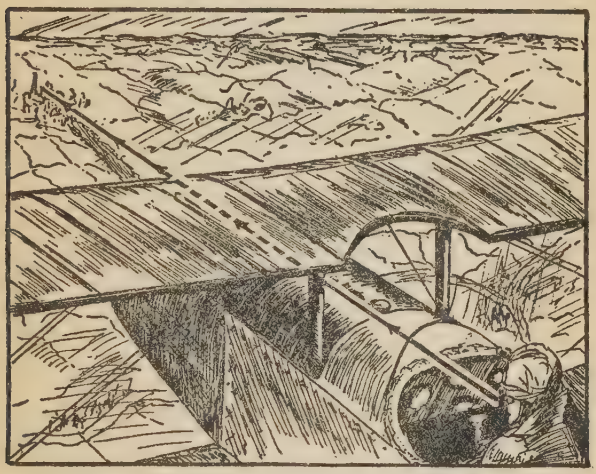

FIG. 30.—Flying straight with the aid of land marks.

sighting the nose of the plane on some distant hill or other landmark, press one foot forward a little, watching the effect upon the flight path of the plane (see Fig. 30). It will turn off toward the side of the foot pressed forward. In order to bring the plane back to its original path again, the student will have to move the rudder bar slightly in the opposite direction, centralizing it when the nose of

the airplane is again pointing toward the distant landmark. Gentle turns like this should be tried for a few moments in order that the student may become thoroughly acquainted with the feel of the rudder control.

Now the instructor takes the rudder control and gives the student the signal to grasp the control column and try the elevators. Do not hold the stick tightly. Take it with the right hand and hold it lightly, remembering that the control of an airplane is essentially delicate. No harsh, rough actions are necessary. Now move the control stick forward an inch or two. Watch the horizon ahead and notice its position in relation to the undersurface of the top wing. The horizon will appear to rise, while pulling the stick back slightly will cause the horizon to sink back. Such, to the pilot, is the appearance of the airplane gliding or climbing as a result of movements of the elevator control. The student will find it very easy to move the control stick, and after a few minutes' practice he will have gained the "feel" of the elevator control.

It is sometimes a help for the student, before going up, to stretch a string tightly across between the two front center section struts to serve as a sighting line for determining the fore-and-aft attitude of the plane in flight; in other words, to show him whether he is climbing or diving the machine (Fig. 31). However, while this is a good thing to do during his early instruction, the student pilot should cultivate the habit of sensing whether

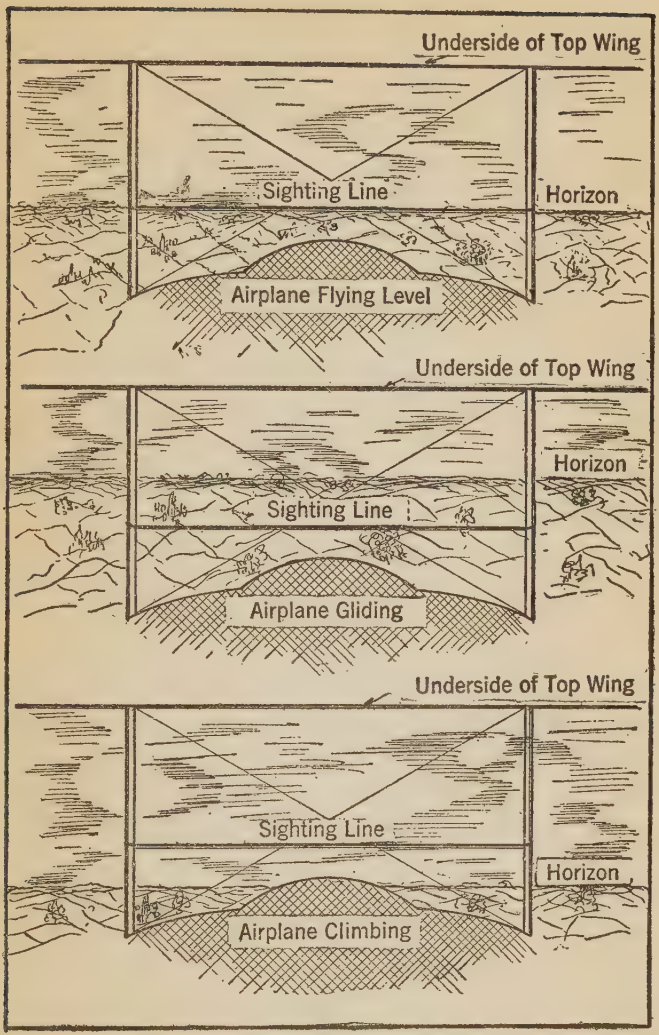

FIG. 31.—Checking horizontal flight against the horizon. Relative angle of climb or dive can be determined in this manner.

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his plane is flying level or not. This will not be difficult.

After practicing with the elevators until he has become thoroughly accustomed to the fore-and-aft control of the airplane, the student should practice with the rudder and elevators together. He will probably find it a little difficult, at first, to keep the machine flying perfectly straight and maintain a level course with the elevators; but a little practice, together with the encouraging comments of the instructor, will demonstrate to the would-be pilot that it is really not difficult after all.

Before the student can say that he has flown an airplane, however, there is one more control to be mastered, namely, the lateral control with the ailerons. This should be practiced in the same manner as previously described, the instructor taking care of the rudder and elevators, and the student gaining an impression of the feel of the lateral control by moving the control stick from side to side and watching the wing tips go up or down, depending upon which way he moves the stick. Moving the stick to the right will depress the right wing, and vice versa, the student judging the attitude of the airplane by sighting the wings (or his "sighting line") on the distant horizon.

After practice with the ailerons, the student should be able to take complete control of the airplane in the air. With his feet on the rudder bar and hand on the stick he should be able to maintain the machine on an even straight course without the

slightest difficulty. Gusts of wind will tend to raise one or other wing tip but a slight movement of the control stick in the direction of the raised wing will instantly correct this.

Of course, the student will probably have made several flights by the time he reaches this stage, since it would not be wise for him to attempt to absorb too much at a time. He will probably have been impressed with the feeling of security and steadiness when controlling the machine. When he uses the rudder slightly it is the object on the horizon, not the airplane, which appears to move around. When he climbs or dives a little or uses the ailerons for raising one wing, it is not the airplane which seems to change position but the horizon. Such is the steadiness which characterizes the flight of a modern airplane.

The pupil is now ready to undertake gentle turns and master the more complicated uses of the three controls of his airplane. How many of us, on our first bicycle rides, endured a spill or two when we came to a corner because we did not know how to execute the turn! Were it not for the fact that airplanes, high up and in full flight, when controlled incorrectly, do not spill with anything like the disastrous results of bicycle riding, there might be many would-be sky pilots nipped in the bud at their first attempt to make a turn in the air!

Just as, when cycle riding, our first efforts at turning corners came to grief because we failed to swing over on the turn, so in the air, the student

pilot, unless he is going to fail utterly in flying his airplane in a curve, must learn to bank the plane in the proper manner and to the correct extent. He will be comforted in learning, however, that nothing more serious than a rapid sideslip inward or outward will result from any error he may make during his early attempts at circling flight—and in the air there is plenty of room for sideslipping provided you fly high enough.

The instructor will take the plane to an altitude of 2000 feet or so before the student should attempt turns himself. This will give him plenty of altitude to allow for his possible mistakes and leave time for the instructor to correct any serious error that the student may make. From his previous practice, the pupil will have become fairly proficient in maintaining the airplane on a straight, horizontal course. To attempt a turn to the left the student will first put on a little left bank, moving the stick gently toward the left, thus depressing the left wing by means of the aileron action. As he does this he must move forward his left foot, which, with his other foot, is on the rudder bar. This will pull the rudder over to the left and the machine will start to turn.

(The reader should practice this, sitting in an upright chair using an imaginary rudder bar and control stick. Visualize the conditions and when the time comes for actually trying it this preliminary "practice" will prove of great value.)

The student will probably have put on too much

PLATE VI.

A "fly-about" type. The DeHavilland "L'Oiseau-Mouche" 6 horsepower single-seat plane on which the well-known British pilot Alan Cobham once flew from London to Brussels.

bank at first and will be sideslipping inward violently. This he will know because of the side draught which strikes the left side of his face. He must ease off the stick a little—not too much or he will start to sideslip outward due to the insufficient bank for the radius of the turn. Of course, the sharper the turn, the greater the angle of bank necessary.

The pupil may find he can make turns in one direction with greater ease than in the opposite direction. This is due to a natural, though unconscious tendency. If this is the case, he should pay particular attention to overcoming this onesidedness and becoming equally proficient in making turns either way since otherwise he will find it a great handicap in his future flying.

After he has practiced easy turns for some time the student flier is ready to undertake turns of smaller radius; in other words, sharp turns in which because of the three dimensional character of the control of an airplane, complication enters. In this connection, it must be borne in mind that the rudder and elevators have their respective control effects upon the airplane only in relation to the machine itself and irrespective of the attitude of the plane.

We have learned how gentle turns are made. Now consider what happens when the machine is made to execute a vertically banked turn and is on its side relative to the horizon. Take, for example, the case of a right hand turn. Right rudder will, regardless of the attitude of the plane, always cause

the nose to move around in the direction of the right wing tip. But, judging the position of the machine from the point of view of the horizon, right rudder, when the plane is in a vertical bank with the right wing low, will cause the nose to drop below the horizon. Left rudder will have an opposite effect, causing the nose of the plane to rise.

Now, take the elevator action when the plane is in a steep right bank. If the control stick is pulled back, it will cause the nose of the machine to move toward the top wing, but, in its present position, this will mean hastening the turn. Thus, it will be realized that during sharp turns the elevator and rudder controls are completely reversed, the rudder trimming the nose of the plane on the horizon and the elevators turning the plane. At turns of 45 degrees, the rudder acts half as rudder and half as elevator while the elevator, too, divides its action in the same way. This reversion of the controls is probably one of the most difficult things a student has to master in learning to pilot an airplane, for steep turns are essential and he must know how to execute them.

Now let us try the steep turn ourselves. At the signal from the instructor the pupil takes the controls and starts the turn—say to the right. The turn is started in the customary way which has already been practiced and is made sharper and sharper until the plane is more or less on its side. Now is the time to start trimming the nose of the machine on the horizon with the rudder. Ease off

the rudder gradually as the turn steepens, using right rudder to bring the nose down and left rudder to raise it with respect to the horizon. Pull the stick back as the rudder is eased off so that the elevators will hold the plane in the turn. Fig. 32 will indicate clearly the progressive steps in manipulating the controls and Fig. 33 the result.

By this time the horizon will be sweeping around past the student's eyes, so that he will probably begin to lose his bearings. However, practice will overcome this, and it would be well if he were to allow the instructor to fly him in continuous sharp turns in either direction until he has become thoroughly accustomed to the sensation.

To come back to our turn, we are probably sideslipping all over the sky by now, but practice only will make perfect, and a little sideslipping will not hurt us provided we have sufficient altitude. While the stick is pulled back to hold the plane in the turn, it will be found that the bank of the machine is inclined to grow steeper owing to the increased speed and lift imparted to the left wing tip which is uppermost, so that it will be necessary to ease off the bank a little by moving the stick—still held back —a little to the left. Once the correct position of the controls has been found the plane will be found to turn 'round and 'round without loss of altitude, and, of course, without sideslipping.

To get out of the turn the first thing the pupil must do is to ease off on the bank by moving the stick gently to the left. As this happens, the ma-

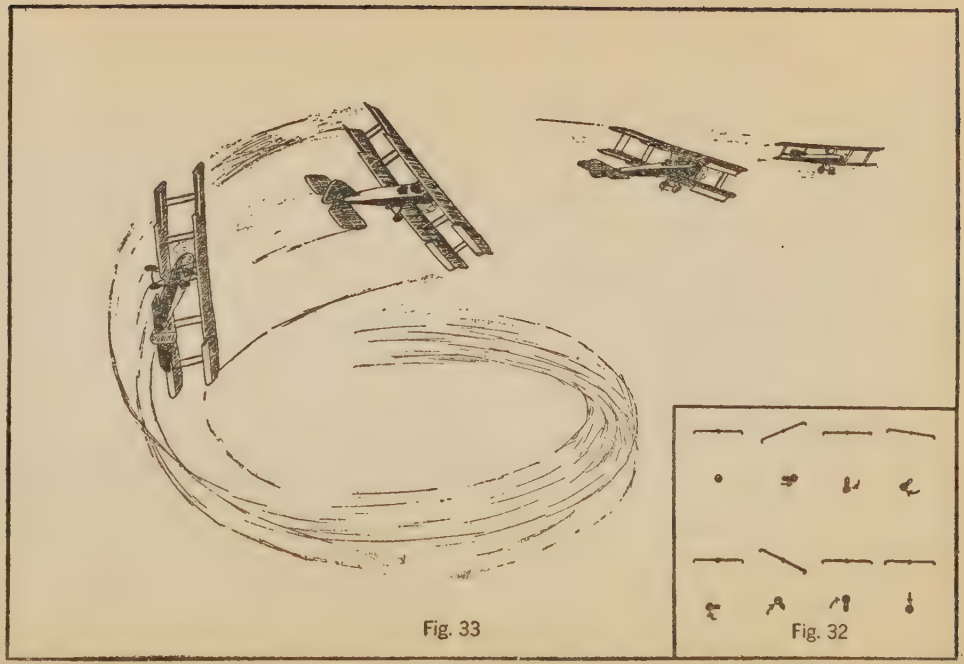

FIG. 33.—Executing a right-hand vertical turn. Fig. 32 represents the control stick and rudder bar positions during the maneuver, reading from left to right. The round dot is the handle of the control stick and the short extension shows its relation to the neutral position.

chine will start to sideslip outward, unless the radius of the turn is enlarged. Moving the stick forward slightly will do this, since the elevators are controlling the turn. Continue to reduce the bank slowly and to follow the action with forward movement of the stick until the bank becomes such that the rudder begins to take over the turning of the plane. Here it will be necessary to start trimming the nose of the plane with the elevators once more and easing off the turn with the rudder.

All this sounds very complicated, but the student can rest assured that it is a knack which a little practice will acquire after which it will come naturally. The pupil should practice right- and left-hand turns in this way and should carry out sharp figure-of-eights in order to get the habit of swinging gracefully into steep curves—one of the most picturesque maneuvers of flying.

It may seem strange that, as a would-be pilot, we are being taught how to fly our airplane thoroughly well while we still do not know how to take off or land the machine. Of course, it must be remembered that while we appear now to possess a thorough knowledge of how to fly the plane, we still lack that experience which is very essential to success, and taking off and landing are more advanced maneuvers.

We are now ready, however, for our first lesson in taking off. In the first place we must remember always to make the take off—and likewise the landing—against the wind. This point has been brought

out before, but is so extremely important as to withstand repetition. Suppose, for example, that there is a wind blowing at 10 miles per hour and that the minimum flying speed of the airplane is 45 miles per hour. Taking off *against* the wind will mean that the ground speed at the moment of leaving the surface will be 45 — 10 or 35 miles per hour, and in landing under the same conditions the wheels will touch at a speed over the ground of 35 miles per hour. If the two maneuvers were undertaken *with* the wind instead of against it, the ground speeds in each case would be as high as 45 + 10, or 55 miles per hour and it is obvious that not only would the machine have to run further in getting off but the landing run likewise would not only be longer but considerably faster, which means an increased hazard. Reference to Fig. 34 will add clarity to this point.

The airplane is, therefore, placed so that it faces into the wind and the engine started. At this time, not all small airplanes are fitted with engine starters and it is, therefore, a good time for the pupil to know how the engine should be started up. This is done by what is called "swinging the propeller"; in other words, the propeller must be swung around in order to give the engine the initial turnover after which, as in an automobile, it should start off itself.

This operation must be performed with the greatest care. The explosive mixture for the start must be sucked into the cylinders by turning the propeller with the ignition switch off in order that there shall be no pre-ignition and back fire. Then, and not until

FIG. 34.—Effect of wind on path of climb in taking off

then, can the switch be turned on and the propeller blade finally swung around for the start, the mechanic being careful to swing his arms out of the way as the propeller begins to turn.

When ready to suck the mixture into the cylinders, the mechanic shouts "Switch off!" Whereupon the pilot, after looking to see that the switch is off, replies, "Switch off!" The mechanic then turns the propeller until sufficient mixture has been sucked into the cylinders. When ready to start the engine he shouts, "Contact!" The pilot switches on and replies "Contact!" the mechanic immediately swinging the propeller over compression and the engine should start. The use of the term "Contact" is in order to avoid possible confusion which might result from the use of both "Switch off" and "Switch on," and the repetition has become practice as an assurance that the pilot understands the mechanic's signals.

The engine started, the time has come for the actual take off. This maneuver is really nothing like as difficult to execute as is usually imagined. Having made certain that there are no obstructions ahead and that no other planes are in the act of taking off or landing, the student opens the throttle gradually until it is wide open and the machine begins to amble forward. (See Fig. 35.) The control stick must now be moved forward slightly to raise the tail off the ground and enable the plane to gather speed. Care must be taken that the tail is not raised too high or there will be the possibility of the pro-

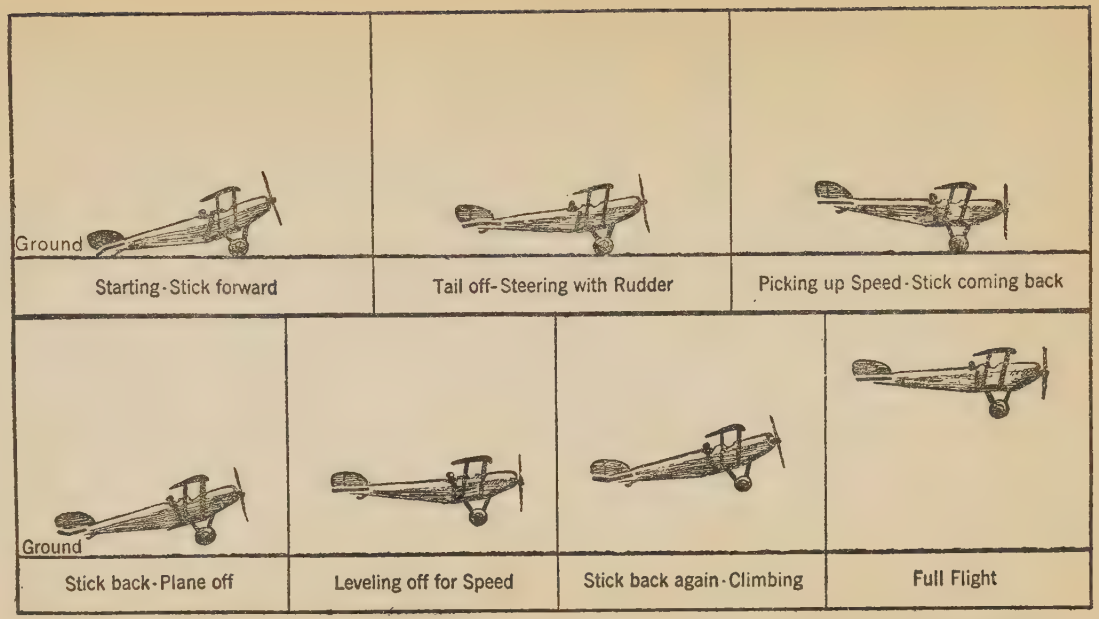

FIG. 35.—The seven stages in the maneuver of taking off. The movements of the control stick and settings of the elevators are indicated.

peller blades hitting the ground. The instructor will be keeping a close eye on this and the pupil should have no fear of making a mistake.

The plane is now speeding at ever increasing pace across the airdrome. Should the machine tend to swing sideways, this can be counteracted by rudding in the opposite direction. Care must be taken not to over-correct with the rudder or the swing will be immediately reversed, the plane swinging the opposite way too far. The rudder should be eased off as soon as the machine starts to turn in the required direction.

After a few seconds the plane will be traveling over the ground at a little over its minimum flying speed. Only experience can indicate to the student when this speed is reached. He may use the air-speed indicator, but it is a poor plan to become dependent upon this indicator, as some day it may prove defective. As flying speed is approached the stick must be very gradually pulled backward. The motion must be very slight or the plane will take off too rapidly, lose flying speed and fall back again.

As soon as the student feels the machine in the air (all bumping on the wheels will cease at this moment) he should ease the stick forward again very slightly in order to permit the plane to gain a little more flying speed since it is bad for the young flier to attempt to climb the plane with too small a margin of speed. After a moment or so of level flight, the machine can safely be climbed to a few hundred feet, flying straight. Remember that it is always

poor piloting to attempt to turn an ordinary airplane near the ground because there is little altitude in which to correct bumps, sideslips, etc. The young pilot should keep on climbing in a straight line until an altitude of from 500 to 1000 feet is attained at which time a turn may be made.

So much for the take off. The maneuver is extremely easy to execute and with a little practice the student will become very proficient. He should remember that no attempt at taking the air should be made if there is another airplane maneuvering overhead preparatory to landing. The machine in the air about to land, according to the air traffic law, has the right of way and must be allowed to exercise this right in all cases except where the landing field is of unusual size such as to permit the machine about to take off getting well out of the way of the alighting plane.

Bringing an airplane in to a landing is, without doubt, considerably more difficult than is taking off. Like all the various phases of flying, however, practice makes perfect and we will now pass on to a consideration of how the pupil is to land his machine and bring his flight to a satisfactory termination.

Landing is not difficult, but it calls for a degree of judgment which is only acquired, firstly, through an exact knowledge of how the thing should be done and, secondly, through practice and experience. The best way for a student to become proficient in landing is for him to practice continually, making short circuits of the field—taking off, flying,

round once, landing again, and so forth. The instructor, at the end of each circuit, will then be able to point out to the pupil where he has erred.

Remember that, like taking off, landings should only be made into the wind. Sideslip landings and crosswind landings are all very well for the experienced pilot, but during his early flying days the rigid law to the student-pilot must permit only of windward landings. The great art of successfully landing an airplane is in knowing where and at what height the engine must be throttled. The engine should never be switched off entirely since the forward speed of the plane might be insufficient to keep the propeller rotating and a later desire to switch on the power once more would thus be frustrated. On most airplanes the throttle lever is adjusted so that when it is moved to the "Off" position it still permits the engine to turn up from 200 to 300 revolutions per minute.

It is virtually impossible to explain, other than in actual flight, just when the engine should be switched off prior to making a landing. Assume, for example, that the student is flying at an altitude of 500 feet, with his instructor occupying the forward cockpit. The flying field is beneath and the time has come to make a landing. The student will fly well out away from the field in such a direction that when he turns to face the field he will be flying into the wind. In flight the student must at all times be aware of the wind direction with relation to his course. This he can ascertain by watching the smoke

from chimneys or keeping an eye on the wind cone on the airdrome hangar.

Now the glide for the landing starts. The engine must be partially throttled and the nose put down into a slight glide. As the field is approached and altitude is lost, the position will be reached when, at about 300 feet altitude, the throttle must be closed. Until such time that the student has had sufficient experience to be able to judge for himself, the instructor will give the signal for this action.

Then begins the landing glide into the field. (See Fig. 36.) The student must watch closely the tops of trees or buildings passed over as he holds the plane firmly, but not roughly, in its steady glide. Watching the ground ahead of him carefully, the student-pilot must make certain that there are no airplanes about to take off. Although, by the rules of the air, he has the right of way, being pilot of an alighting aircraft, this is no reason why he should not exercise the greatest diligence in avoiding the possibility of interference.

In the event that he overshoots his mark (the imaginary spot on the field at which he expects to bring the plane to earth) or if he sees that he is going to undershoot, it is a good plan to switch on the engine and proceed to make another circuit in order that he may give himself the best chance possible of effecting a good landing. Of course, in the event of undershooting, it is always possible for the pilot to switch on the engine momentarily in order to gain the necessary distance and then proceed to

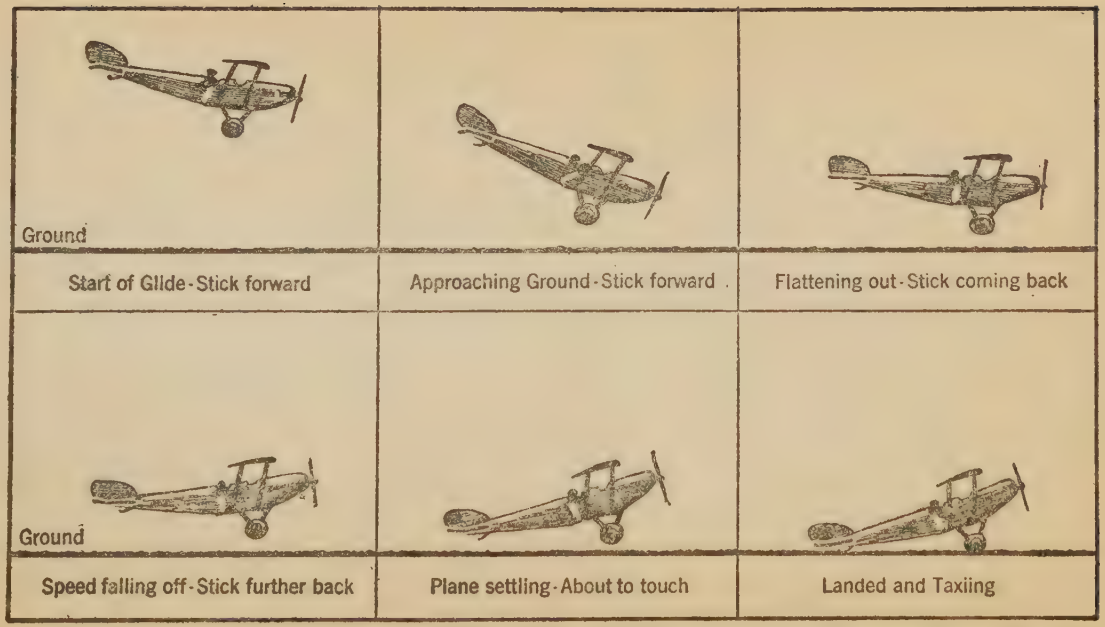
Ground
Start of Glide - Stick forward
Approaching Ground - Stick forward
Flattening out - Stick coming back
Ground
Speed falling off - Stick further back
Plane settling - About to touch
Landed and Taxiing

FIG. 37.—The six stages in the maneuver of landing. The movements of the control stick and settings of the elevators are indicated.

land. This, however, is likely to put the young flier off his judgment and is, therefore, not to be recommended. It is far better to execute another circuit and make a clear start again.

Assuming that the student sees that he is going to reach the field at just the right time and altitude, he must watch the earth most intently, maintaining all the time the correct glide and speed. When the plane is within 20 or 30 feet of the ground it is time to begin almost imperceptibly flattening out of the glide by manipulating the control column accordingly. Still watching the ground 20 yards or so ahead, the pupil continues to pull the control stick back gently until he gradually increases the angle of incidence, and finally as flying speed is lost, the wheels glide gently onto the surface of the field without a jerk of any kind with the exception of the immediate bumpiness which begins as the wheels roll over the rough ground.

In easing back the control stick, it may be necessary at times to pause momentarily, or even to reverse the movement slightly if the preceding backward movement has been made too suddenly. The whole art of landing consists in timing accurately the relative positions of earth and airplane, the eye working in close unison with the hand. It is extremely important that the rudder be kept straight at the moment of landing, otherwise side loads which may become serious due to the plane veering off will be set up in the undercarriage. Having touched the ground, the tail must be held down firmly

in order that it may drag and so reduce the ensuing run.

Without doubt the most difficult phase of the operation of landing is at the moment just before touching. At this moment the student-pilot can make one of two mistakes. He can either fail to flatten out in time and thus fly into the ground, demolishing the undercarriage and generally smashing up the plane, or he can flatten out too soon. The latter will result in what is called a "pancake landing," which means that the airplane "lands" two or three feet above the surface of the ground. The resultant drop may or may not result in smashing the undercarriage but in any case will shake up the occupants of the machine and must, therefore, be avoided.

The student-pilot will find landings quite easy after a little practice and he should take every opportunity of getting this practice. He should practice landing in a small section of the airdrome so that he may acquire the facility for getting into and out of small fields, which he may frequently want to do during his subsequent cross-country jaunts. In maneuvering into small fields it is frequently necessary to lose altitude without covering much ground. In such circumstances, diving will not do, since this would result in greatly increasing the speed, which would probably end in the pilot's overshooting the field altogether.

In a case like this the best procedure is to make a series of "S" turns during the approach to the

field. In executing these turns always turn toward the field and watch carefully the changed relative position of the field at each turn so that when the moment comes to stop turning and to glide in, the opportunity will not be missed. The "S" turn enables the pilot at all times to keep his eyes on the field, whereas a spiral would not permit this.

Only practice can make perfect, and what may seem difficult or complicated at first sight is very soon resolved into marked simplicity through practice. No one can learn to fly an airplane by reading about it any more than an automobile driver is made anywhere else but on the road. There is not the slightest doubt, however, that the student who has a thorough knowledge of how and why his airplane flies and how it is built, together with at least a broad imagination of how the machine should be controlled, will make a much better pilot in shorter time and with far less grief than otherwise. Flying is fascinating and flying is simple, as this discourse has endeavored to show.

CHAPTER VI

Engines for Aircraft

It has been said, and rightly so, that the very heart of an airplane is its engine. The whole history of flight is one in which the development of satisfactory powerplants has played a paramount part. It was, in fact, not until the introduction of the small, high-speed gasoline engine that mechanical flight became a possibility. Other sources of power which had been employed in experiments by the pioneers had proved both too bulky and excessively heavy, and it was the small 12-horsepower gasoline engine developed by the Wright Brothers which made possible the transition of their research from pure gliding tests to actual power flight experiments. In spite of its comparatively heavy weight, over 12 pounds per horsepower, this engine was so much lighter and smaller than similarly powered units of other types that it spelled the difference between success and failure in the work of the Wrights.

From the first successful airplane gasoline engines have been developed the modern highly efficient aircraft engines of today. As a result of the co-operation of automotive engineers we have at this time

aircraft engines which are both the most powerful and at the same time the lightest power units ever produced, developing, as they do, up to and even exceeding 1000 horsepower in single units and weighing as little as one pound and less per horsepower.

The fundamentals of an airplane engine are those of an automobile engine, with suitable adaptation to the specific requirements of flying. Because, in an airplane, flight depends so much upon speed, it is obvious that reliability in the engine is in reality synonymous with reliability in the airplane. It should be remembered, of course, that a failure in the powerplant does not by any means spell an accident, although it does inevitably mean the foreshortening of further flight. For this reason, then, reliability and dependability are fundamental requirements in an aircraft engine—more so than in the case of any other class of power unit.

Another specific requirement of an airplane engine is light weight for the power developed. That is, while the power must be high the weight of the complete engine ready to run must be as low as possible commensurate with strength. Furthermore, this question of weight involves also the fuel and oil consumption of the engine which must be reduced to a minimum in the case of aviation engines for reasons other than mere economy. It must be understood that the weight of an aircraft engine is to be considered not as the bare weight of the power unit, but as including all equipment and an amount of fuel and oil sufficient to fly the machine for a

given distance or a given time, since this quantity of fuel and oil must be carried in the plane at the start of the flight.

These are the problems upon which aircraft engine designers have been and are continually working. And their difficulties are by no means lessened by the inherent restrictions upon their scope. An airplane engine must be small in dimensions in order that it may be squeezed within the narrow confines of the airplane fuselage and not present a high resistance to the airflow by extending outside of its cowling more than is necessary. Again, there are few mechanisms which require more careful balancing than the airplane engine since the slightest lack of balance will cause excessive vibration against which the comparatively light structure of the engine bearers will be inadequate to stand. If vibration is permitted to grow it will soon spell heavy wear and tear and eventual breakdown in the engine, followed by general loosening up of the airplane structure itself.

With all of these seemingly difficult problems the aircraft engineer is contending successfully and the result is that in commercial aircraft operations today, the failures due to engine trouble are becoming comparatively few, the larger proportion of mechanically interrupted flights being due to trouble with equipment and installation rather than in the power units themselves.

The majority of airplane engines are designed to operate on what is known as the "four stroke

cycle," meaning that for every power stroke there are three other strokes to make up one complete cycle.

Whether an automobile engine or an aircraft engine, its operation is based upon the power developed by the timely explosion of a mixture of gases inclosed and compressed within one or a series of cylinders. An accurately fitting piston is made to slide up and down within a cylinder by means of a connecting rod working on a rotating crankshaft. Two openings fitted with valves are arranged in the head of each cylinder for the purpose of introducing the combustible gases prior to explosion and withdrawing them after explosion. These valves are known, respectively, as the inlet and exhaust valves and their timely operation is actuated by means of suitable mechanism in the engine.

At the beginning of the cycle, the piston is at its highest position in the cylinder and the inlet valve is open (Fig. 37, A). The piston recedes and a quantity of explosive mixture is sucked into the cylinder until the stroke is concluded, at which time the inlet valve closes, rendering the space in the cylinder above the piston airtight. In this condition the piston rises again on the second stroke (Fig. 37, B), and compresses the explosive mixture into the cylinder head.

Just at the moment of the beginning of the third stroke the compressed gases are fired by an electric spark from a plug set into the cylinder wall, which in turn is charged by means of a magneto, the cir-

cuit breaker of which is timed to close at the correct moment and cause the explosion which results in the

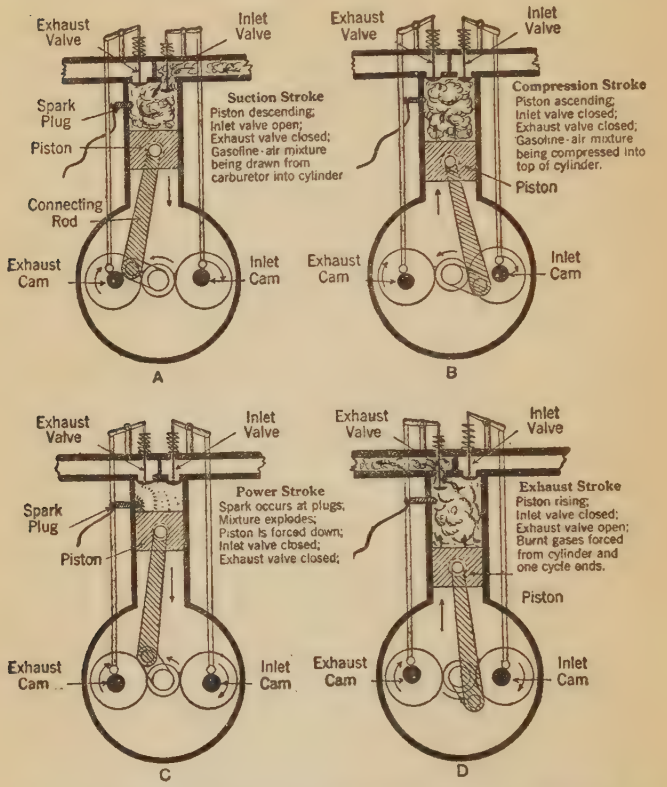

FIG. 37.—The principle of the four-stroke engine, illustrating the cycle of operation.

power stroke (Fig. 37, C). At the conclusion of this stroke the exhaust valve is opened by a cam mechanism and the fourth stroke, a rising stroke

(Fig. 37, D), expels all of the burnt gases, which escape through the exhaust manifold. The cylinder is now ready for the next cycle.

The four strokes which constitute the cycle are known, respectively, as the suction stroke, the compression stroke, the power stroke, and the exhaust stroke.

Very naturally, with but one power stroke to each cycle the running of an engine formed of only one cylinder would be somewhat uneven. For this reason it is customary to find internal combustion engines, either for automobiles or for aircraft, employing a multiplicity of cylinders, ranging anywhere from two up to twelve, and in exceptional cases even higher. Before we pass on, however, to a consideration of the various forms and types of aircraft motors it will be well to give some thought to the several component parts, generally referred to as equipment, which are an intimate part of the power unit.

It will be recalled that two things have been accepted without explanation, namely, the introduction of a gaseous explosive mixture into the cylinder through the intake valve and the emission of a spark for igniting the mixture of gases at the proper moment. The question immediately arises—how is it that liquid fuel is poured into the fuel tank and yet the fuel which passes into the engine proper is a gaseous mixture of gasoline vapor and air? And again, what causes the timely electric spark?

These points are really quite simple to explain.

They constitute the very basis of the operation of gasoline engines whether for automobiles or aircraft. In the first place, it must be realized that gasoline, while being extremely inflammable is not explosive unless mixed, as a vapor, with air in the correct proportions. In an internal combustion engine vaporization and mixing is achieved by means of what is called a "carburetor." This is a small piece of apparatus through which the fuel passes before reaching the engine cylinders for detonation, and the process is called the "carburetion" of the fuel.

The carburetor consists of two main parts, the most important of which is the mixing chamber and that of secondary importance, the float chamber. Referring to the diagram (Fig. 38) it will be seen that the mixing chamber is connected at its upper end with the tube or manifold leading to the intake valves of the cylinders while its lower end is open to the atmosphere. In the mixing chamber is a jet consisting of a tube brought to a very small orifice situated in the middle of the mixing chamber at a point where it is narrowest.

The jet in the carburetor fills with gasoline. On the first downward stroke of the piston in the cylinder, namely, the suction stroke, air is drawn rapidly through the mixing chamber, its speed being of necessity greatly increased as it passes the narrow portion (since the same amount of air must get through a much smaller space in the same time). This fast moving current of air sucks up a small

quantity of gasoline from the head of the jet. As the fuel emerges rapidly out of the small hole in the jet it is separated into a vast number of minute particles which cause it to vaporize with great rapidity and mix with the inrushing air to form a highly combustible gaseous mixture, the gasoline content of which can be varied by adjusting the size of the jet.

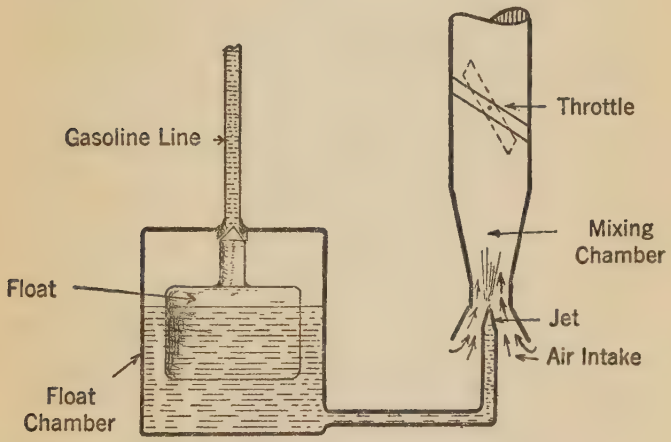

FIG. 38.—The operation of the carburetor.

If the jet of the carburetor were connected direct with the fuel tank there would be nothing to prevent gasoline flowing freely out of the nozzle and overflowing. This is obviated by means of the float chamber which is merely a small reservoir the purpose of which is to regulate the level of the gasoline flowing direct to the mixing chamber so that this level is at the same height as the head of the jet.

This is achieved by means of a small cylindrical metal float usually made of thin brass. As the gasoline enters the float chamber the float rises until, at the predetermined height of the liquid, a small needle valve stops any further flow.

When the engine is at rest no more than a given quantity of fuel can enter the float chamber but when running the inrushing air through the mixing chamber continually sucks gasoline out of the nozzle of the jet tending to empty the float chamber. As the level of liquid in this chamber drops the float will automatically open the needle valve and permit more gasoline to enter to maintain a constant level feeding the jet.

The speed of the engine is regulated not by altering the gasoline flow from the jet, for this would merely alter the efficiency of operation of the engine. since it would vary the strength of the mixture. Engine speed is controlled by limiting the quantity of mixture of a constant, or more or less constant, proportion, which is permitted to enter the cylinders on the suction strokes. To achieve this end what is known as a "throttle" is employed, by means of which the outlet from the mixing chamber to the cylinders is varied, thus permitting a greater or lesser quantity of explosive mixture to enter the cylinders through the intake valves.

We have supplied the means whereby the liquid fuel is served to the cylinders in the necessary gaseous state for explosion by means of the spark which we have yet to provide. The sole purpose of the

spark is to ignite the explosive mixture within the cylinder at the moment when the power stroke of the piston is about to commence and the gases are, therefore, under high compression. The problem, it will be seen, is to provide a means for creating a very hot electric spark in the cylinder at exactly the correct moment. The difficulty of doing this is the fact that the higher the pressure within the cylinder the harder it is to cause an electric discharge to jump between two points or electrodes. However, with the aid of high tension electric magnetos this has been found possible and for this reason the magneto is another of the important parts of the internal combustion engine.

If a coil of copper wire with its ends joined is placed near the end or pole of a magnet and is moved so that the coils cut across the so-called lines of magnetic force surrounding the magnet, a current of electricity will flow through the wire in a certain direction. This is a long discovered phenomenon of magnetism and electricity.

In order to utilize this phenomenon, suppose that instead of using an ordinary bar magnet, a horseshoe type magnet is employed (see Fig. 39). The most convenient method of moving the wire near the magnet is to wind it upon a suitable former called an "armature" and rotate it between the poles of the magnet. Since the faster the movement the greater the electric current induced in the wire, the armature must be rotated at high speed and it will be obvious that the revolving of the armature causes

the induced current to alternate rapidly since the winding of the wire changes direction every half revolution with relation to the poles of the magnet.

It has been found that the electricity so induced into the coil of wire, which constitutes what is termed a primary winding, is of low pressure and,

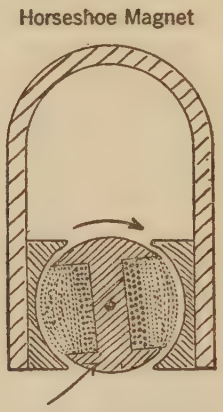

FIG. 39.

therefore, incapable of overcoming the resistance necessary to cause it to spark across the small gap between the two points of the spark plug in the cylinder.

Another coil of wire is, therefore, wound over the primary, this latter being known as the secondary winding. If a steady electric current were flowing in the primary there would be no influence

exerted upon the secondary winding. However, since the current in the primary winding is alternating rapidly, the impulses in the one winding create electric current in the other through magnetic influence. (It has been explained that moving a coil of wire near a magnet causes electricity to be generated. It is reasonable to suppose, therefore, that causing electricity to flow in a coil will, conversely, be the means of generating magnetism. This proves to be the case provided the primary current is alterating.)

Thus, a flow of electricity is induced in the secondary winding by the alternations of the primary and by giving the secondary coil many more turns of wire than the primary the secondary current will have many times the pressure, or voltage, of the former. This high pressure is sufficient to cause an electric spark to jump the tiny gap between the points of the spark plug and fire the explosive mixture within the cylinder. A suitably arranged contact breaker rotates with the magneto and times the spark to synchronize with the power stroke of each cylinder of the engine which itself drives the magneto.

Thus, we now have all of the essential requisites for the operation of the aircraft engine, having provided in the form of a carburetor a means of manufacturing the correct gaseous mixture which, when exploded, supplies the power in the cylinders and the magneto for firing this mixture at the correct moment. We can now pass along to a consideration

of the various types of engines used in aircraft, the fundamentals of operation of which engines will in all cases be identical.

It has already been indicated that with only one stroke developing power in each cycle (four strokes) of the engine, a unit with but one cylinder would run very unevenly. For this reason it is usual to find the larger internal combustion engines used in the automotive and aviation fields provided with a multiplicity of cylinders each with its piston rod working upon an individual "crank" of the crank-

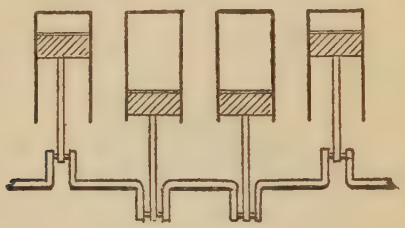

Fig. 40.

shaft, as shown diagrammatically in Fig. 40. An engine of this nature may have any even number from four up to twelve cylinders and at times even more. In the diagram the four cylinder type is depicted, the larger engines with more cylinders being similar in general with the exception that the crankshaft arrangement is of necessity more complicated. A larger number of cylinders are made necessary when greater power is called for since, to a large extent, the power of an engine is determined by the cubic capacity of its cylinders.

There are a number of different arrangements adopted by engine designers in overcoming the problems attendant upon increasing the number of cylinders of an engine to provide for the higher powers. A four-cylinder or a six-cylinder engine will have the cylinders arranged in a single line as shown in Fig. 41, a, and is termed an "in line" engine. If a large number of cylinders are used, for example, eight or twelve, it is customary to split the cylinder arrangement into two banks of four or six cylinders, respectively, per bank (Fig. 41, b). Such an engine is known as the "Vee" type. This arrangement of the cylinders is made necessary in larger engines by the fact that were the cylinders to be arranged "in line" the engine would be excessively long, a disadvantage in aircraft practice as well as in automobile work, if for no other reason than that of the high torque stresses which would be set up in the very long crankshaft necessary. By adopting the Vee type the crankshaft arrangement is somewhat more complicated but the engine is a much smoother running mechanism and has other advantages attendant upon its compactness.

In very large engines using twelve and even more cylinders the "arrow" and "X" arrangements are sometimes adopted, as shown in Fig. 41 (c) and (d), respectively. The British Napier Lion twelve cylinder aircraft engine developing 450 horsepower is a typical example of the "arrow" type, with four cylinders to each bank, while the Napier Cub (1000 horsepower nominal) and American Packard ex-

perimental engine developing 1200 horsepower are characteristic of the "X" type which has seldom been employed in the past.

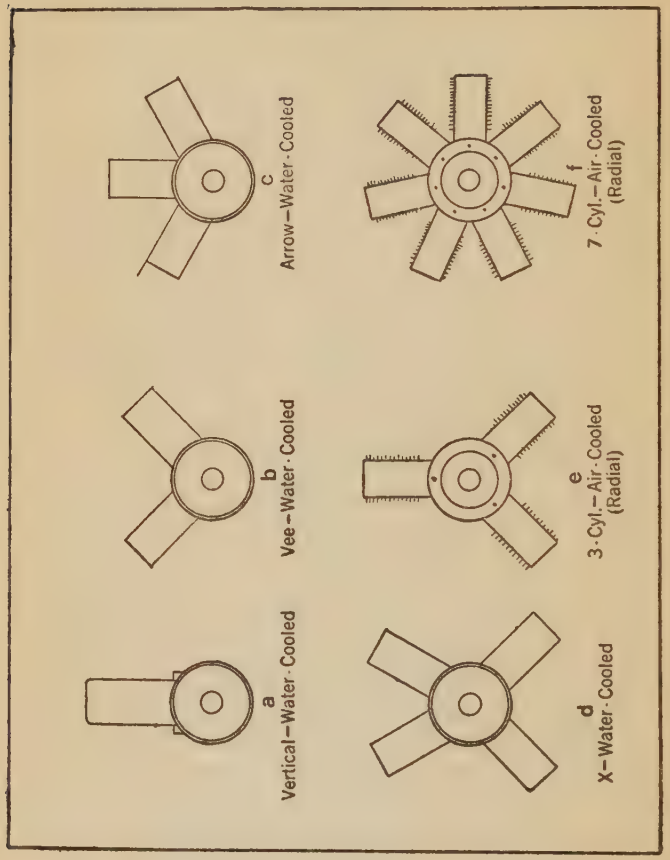

FIG. 41.—Aircraft engine types.

In all internal combustion engines the cooling problem is a major one. Because of the colossal temperatures set up inside the cylinders during the

explosions the motor would overheat were it not for the installation of a suitable cooling system. Obviously, the only way to provide effective cooling is to arrange for the dissipation of the heat of the cylinders. This can be done by transferring the heat to water which is made to circulate between the engine and a radiator exposed to the airstream, where the water is cooled before returning to the cylinders to repeat the cycle. The cylinders are constructed with double walls known as waterjackets and water circulates continually around them and back to the radiator maintaining a normal running temperature in the motor at all times.

While engines of this type, known as water-cooled engines, are in very wide use in aircraft, especially in the higher powers, for many years there has been a school of thought very much opposed to what might be termed an "air-cooled water" system of cooling an aircraft engine. Certainly the opponents of the principle of water-cooling have a very strong case when it comes to the aircraft engine. The airplane is essentially an air-going vehicle in which it would be reasonable to suppose the direct influence of the air itself would be more suitable for motor cooling than any system introducing water which, after all, must itself be cooled by the air stream in its turn.

While direct air-cooling in aircraft engines is by no means a new development it is only comparatively recently that engines of this type have come into popularity. Not only does the air-cooling sys-

tem obviate the complicity of water jackets and radiators together with their necessary piping and the weight involved but the greater reliability achieved as a result of the elimination of so complicated a system is a highly significant feature of the air-cooled type of powerplant.

Because of the necessity of presenting each cylinder itself to the airstream, the air-cooled type of

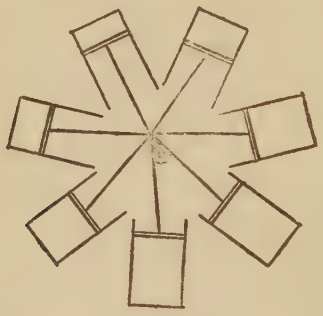

Fig. 42.

engine is usually of what is known as the "radial" type with the cylinders arranged radially around a circular crankcase (crankshaft housing) and all of the piston rods operating on a single crank of the crankshaft, as shown diagrammatically in Fig. 42. Radial engines of the air-cooled type are in use in a wide range of power classes. There are the three-cylinder units of low power (Fig. 41, e) and the five-, seven-, and nine-cylinder motors of proportionately high power output (Fig. 41, f). Engines of this type usually have an odd number of cylinders

because of the better balance and smoothness of running thereby obtained. The well-known Wright Whirlwind (200 horsepower), the engine used by Colonel Lindbergh on the "Spirit of St. Louis" in his several famous flights, is an outstanding example of the air-cooled radial and is the type at present employed in the planes operating on many of the air mail routes throughout the country.

The problem of powerplant installation is a major one to the designer of an airplane. Just as the finest built automobile chassis and body would be of little use were it to be fitted with a poor quality or faulty engine, so it is of vital importance that the aeronautical engineer, after he has produced the finest possible aircraft design, must see to it that the engine of his choice and its installation are faultless.

Much is written and a great deal more is said about engine failures in the air and the resultant forced landings which may or may not end in a crash. The fact remains, however, that the aircraft engine of today is at least as highly developed as the modern automobile engine and in many respects is even superior to the latter. The trouble with the aircraft engine starts—when it does start—with its operation. We would not dream of driving our automobile for hours on end at full throttle, even if it were mechanically possible to do so, but the airplane pilot will frequently so maltreat the aircraft engine. At best an airplane motor is expected to operate steadily for protracted periods at two-thirds

and three-quarters throttle. What wonder that it sometimes breaks down under excessive bad treatment!

While it is perfectly possible, with suitable treatment, as has been demonstrated by Colonel Lindbergh and others, to operate a single-engine airplane indefinitely without failure, it is, nevertheless, necessary in the case of large passenger carrying airliners such as are used on the airways of Europe and will shortly be in regular use in the United States, to have multi-engine equipment. Just as an ocean-going liner would not set out on a long voyage with but one engine, so the multi-engine principle must be made to apply to the safe and reliable operation of the public airways and air services.

The three-engine aircraft, already highly developed both as a land plane and a seaplane, will undoubtedly inaugurate regular passenger transportation by air over the continents and the oceans in the not distant future. Machines of this type cruise with all engines throttled, while the maximum power is always available when necessary, such as during taking off and climbing. Furthermore, the three-engine airliner is designed to be capable of flight without the slightest hazard with any one engine stopped just as an ocean liner is controllable and navigable with one of its turbines laid up. All reasonable reliability is assured in the airliner of the immediate future. With its highly efficient aerodynamic design, its multi-engine powerplant installation and its wings riding on the air with the

rigidity and grip of the automobile on the highway, the modern airliner has made accidents the exception rather than the rule and when this established fact is backed up by public confidence the growth of air traffic will surely be enormous.

THE END.

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